THE USE OF GOAL PROGRAMMING FOR RESOURCE ASSESSMENT, WITH AN APPLICATION TO FOREST ENERGY DEVELOPMENTS IN EASTERN ONTARIO

By

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ABSTRACT

This research was primarily concerned with the identification, development and application of methods for the purpose of providing information to assist resource management decisions. The type of information sought was defined by four questions, which essentially relate to the ability to achieve specified development goals and the identification of conflicts amongst goals. Analysis directed at resolving these questions was referred to as resource assessment.

The first major component of the research involved the search for appropriate methods by which to undertake resource assessment analysis. The ability to account for multiple, and possibly conflicting goals, which may be expressed in disparate metrics, was an explicit concern in evaluating the various methods. Multiobjective goal programming was identified as one method well-suited to resource assessment analysis.

Application of a goal programming model in an assessment of proposed forest energy developments in Eastern Ontario constituted the second major component of the research. This provided an applied context within which to further evaluate the suitability of goal programming for

resource assessment. Application of the method was also expected to provide useful insights into the implications for the Eastern region of forest energy developments.

Results suggest that energy plantation developments could make a substantial contribution to the Eastern region of Ontario, through the development of under-utilized land resources, the generation of regional income, the provision of jobs, and the production of energy for local markets and perhaps beyond. The analysis clearly indicates, however, that conflicts exist amongst the specified development goals. Resource allocations which imply favourable results in terms of one development goal may mean relatively poor achievement levels with respect to some of the other goals. This suggests that considerable caution must be exercised in selecting development strategies with respect to a forest energy system.

The research makes an important contribution in a methodological sense, by demonstrating that scientific procedures can be employed to systematically and rigorously address questions of fundamental importance in resource assessment. In particular, this research has shown that it is possible to assess options in resource use with respect to several, potentially incompatible, goals. By providing useful information relating to the possible socio-economic and environmental consequences of forest energy developments in Eastern Ontario, the research also makes an important contribution in an applied sense.

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INTRODUCTION

1.1 REQUIREMENTS OF A RESOURCE ASSESSMENT METHODOLOGY

Resource management, broadly defined, refers to the allocation of natural environmental assets to end uses. Traditionally, economic and technical efficiency were promoted as the principal concerns in evaluating and selecting between alternative courses of action. The consumption of natural resources and effects of development on environmental quality were of little concern when the prevailing view was that these resources were virtually unlimited in supply and essentially free inputs to production. An increasing awareness of the complex relationships between man and the environment, however, has inspired a demand for more comprehensive assessments of development proposals. In addition, the effects of resource development projects on regional economies, particularly in relation to employment and income generation, and the implications of development for local communities have been cause for increasing concern

(Leistritz and Murdock, 1981). The need to evaluate development projects and proposals with respect to multiple, and often conflicting, goals and objectives is now widely recognized (Lakshmanan and Nijkamp, 1980; Lonergan, 1981; Loucks, 1975; McAllister, 1982; Nijkamp, 1980).

Resource management decisions, therefore, typically necessitate the consideration of multiple evaluation criteria, disparate values and multiple metrics. In resource management, development goals might refer to economic efficiency, maintenance of environmental quality, and improvements in regional economies. For resource managers, assessments of the extent to which various development goals can be simultaneously satisfied is information that would facilitate effective management. Additionally, the identification of potential conflicts between specified goals can assist in designing projects that achieve a balance between objectives.

The capability to satisfy any particular development goal is directly affected by production relationships such as those between quality of land and yield, resource limitations (such as the amount of land available) and institutional factors.

Since most development projects are characterized by multiple goals, resource assessments will also be explicitly influenced by the relative importance attributed

to the individual goals. Alternative priority weightings of goals will typically result in very different assessments, especially when goals are conflicting.

Resource assessment is defined here as an analysis of the extent to which resources have the capability to satisfy development goals. This requires a method by which to address the following question:

1. Given a set of production relationships, resource limitations and institutional factors, what allocation of resources best satisfies the entire set of goals, taking explicitly into account the relative importance attributed to each goal?

A particular answer to this question, in itself, is of limited value, since it depends upon a precise specification of production relationships and resource constraints, about many of which there may be considerable uncertainty. Moreover, individual assessments are based on one particular evaluation of the relative importance of goals, when many alternative ratings of importance often exist. Provided with a technique to address this question, however, the following two important questions might also be addressed:

2. What are the effects upon resource assessments of changes in the assumptions relating to

production relationships, resource limitations and institutional factors?

3. To what extent are resource assessments influenced by the relative importance assigned to the individual development goals?

Answers to (3) will provide the basis for answers to a fourth and closely related question:

4. Are the specified goals in conflict and, if so, to what extent?

The ability to satisfactorily address these four questions is the fundamental requirement of a resource assessment methodology.

The need to account for multiple, and possibly conflicting, goals presents particularly difficult problems in developing a suitable methodology for resource assessment. Although many analysts have attempted to design assessment and evaluation methodologies that are suited to comprehensive analyses, success in these endeavours has been limited. The purpose of the research described herein is to identify a suitable methodology by which to address the questions posed above, and to demonstrate the capabilities of this resource assessment methodology through application to a forest energy project in Eastern Ontario.

1.2 FOREST ENERGY DEVELOPMENTS IN ONTARIO

Increasing awareness of the fact that natural resources are finite has been a fundamental incentive to undertake more careful assessments of their use. In the early 1970's, resource scarcity became a major issue, when the Organisation of Petroleum Exporting Countries (OPEC) withheld supplies of crude oil to the West, and subsequently quadrupled prices. The limits to fossil fuel reserves became widely appreciated. These sources of energy, upon which many countries had become heavily dependent, had previously been regarded as bountiful. The price of energy was low relative to other inputs to production, encouraging disregard for conservation and efficiency in use. Restricted supplies and the dramatic increases in price of crude oil in 1973, and again in 1979, were persuasive reminders that conventional energy sources, like many other natural resouces, are limited in quantity.

An important response to the energy "crisis" has been the development of renewable resources, including solar, tidal, wind and biomass energy sources. Perceived advantages include the fact that renewable energy resources are often ubiquitous and are essentially inexhaustible, they are socially desirable in that development is best

suited to the local scale, rather than large centralized facilities, negative environmental impacts are negligible, and that the development of renewables will contribute to the diversification of energy supply (Friends of the Earth, 1983; Henderson, 1981; Lovins, 1977, 1979; Nash, 1979; Science Council of Canada, 1977). Although some authors view renewable energy as a panacea for the problems of the world (see especially Lovins 1977, 1979), the same caution must be exercised in developing these resources as for any other type of development.

In Ontario, one alternative that has been extensively studied is the development of fast-growing hybrid poplar plantations for the production of biomass to be used as an energy source. Proposed energy end uses include direct combustion for institutional heating, as a feedstock for electricity generation, and as an input in the production of methanol for use as a transport fuel (Peat, Marwick and Partners, 1981a). In addition to providing renewable energy, the establishment of hybrid poplar plantations is considered to represent an important incentive to economic development in the economically disadvantaged Eastern region of the province (Anderson et al., 1983; Peat, Marwick and Partners, 1982; Wayman, 1978).

To date, research has focussed primarily on the technical and management aspects of plantation development (Anderson and Zsuffa, 1983a; Ontario Ministry of Natural

Resources, 1983; Sastry and Anderson, 1980). In addition to technical efficiency, however, a variety of other concerns exist with respect to this resource development. The Deputy Minister of the Ontario Ministry of the Environment, in his remarks in 1980 to the Special Committee on Alternative Energy and Oil Substitution, stated: "We believe that renewable sources of energy deserve serious consideration from the viewpoints of environment, economics, net energy generation and resource utilization" (Canada, Department of the Environment, 1982).

More specifically, concerns for economic efficiency relate to both the biomass production and the energy conversion phases of forest energy developments (Gardner et al., 1983; Moran and Nautiyal, 1981; Peat, Marwick and Partners, 1981a; Pfeiffer, 1978). Questions also relate to the possible contributions to the Eastern Ontario region in terms of employment and income generation as a result of plantation forestry developments (Anderson et al., 1983; Wayman, 1978). In the last decade, concerns for energy efficiency have become more pronounced, particularly in relation to energy projects (Gilliland, 1975; Odum and Odum, 1981), and consideration of the energy consequences of the Eastern Ontario forest energy project is warranted.

Forest energy projects are often regarded as not being disruptive to the environment, and in some respects are considered to be environmentally benign (Rose, 1975;

Wayman, 1978). The possibility of detrimental effects on the environment as a consequence of forest energy developments has also been recognized, however (Canada, Department of the Environment, 1982; Plotkin, 1980; U.S. Department of Energy, 1978; Zsuffa and Morgan, 1983). Effective resource management demands that explicit consideration be given to the potential impacts (positive and negative) of forest energy developments.

The development of hybrid poplar plantations for energy production may have significant regional consequences, and resources must be managed carefully to insure that the greatest benefits are realized, while keeping negative impacts to a minimum. The extent to which specified development goals can be satisfied, if land and other resources are devoted to a biomass energy industry, is information that will assist resource management decisions. In this case, goals might refer to economic efficiency, environmental quality, energy efficiency, and regional employment and income generation, as described above.

1.3 STRUCTURING THE RESEARCH TASK

The specific objectives of the research were to:

1. Evaluate the suitability of methodological frameworks for resource assessment;

2. Select or develop a methodology for resource assessment;
3. Apply the methodology in an analysis of the forest energy plantation project in Eastern Ontario; and
4. Evaluate the methodology in terms of its capabilities for resource assessment.

The following chapter describes the nature and potential of biomass energy, focussing on forest energy plantations. Major forest energy plantation projects throughout the world are described, and forest biomass potential in Canada is considered. The final section describes the hybrid poplar plantation project in Eastern Ontario, considering especially the potential regional consequences of development.

An important component of this research involved the review of various methodological frameworks that might be suited to the research task. In Chapter 3, methods of plan evaluation and impact assessment are discussed. The review considers explicitly the capability of the various methods to address the four questions posed above.

Programming methods are considered to be well-suited to resource assessment as it has been defined here, and both single-objective and multiobjective models are reviewed in Chapter 4. Goal programming is considered to be

a particularly appropriate framework within which to address the questions listed previously, and the general goal programming model is presented and discussed.

A resource assessment framework, based on a goal programming model, was developed to assess options in resource use for renewable energy in Eastern Ontario. In Chapter 5, the mathematical framework is presented and the various data bases are described.

The resource assessment analysis relating to forest energy developments in Eastern Ontario is described in Chapter 6. Attainment levels for individual goals under different goal priority orderings are indicated. This contributes to the identification of the relationships between goals. Analysis is also directed at assessing the effects upon goal relationships of variations in the specified target levels for goals. The effects of varying assumptions with respect to input data are also assessed.

The concluding chapter presents a final evaluation of the method selected, in terms of its suitability for resource assessment analysis. Some final observations on the development of forest energy plantations are also offered. The thesis ends with recommendations for future related research.

CHAPTER 2

FOREST ENERGY PLANTATIONS AND THEIR DEVELOPMENT IN ONTARIO

2.1 INTRODUCTION

The increasing importance attributed to renewable energy is a direct consequence of the oil crises of the 1970's. Dramatic increases in the price of crude oil during the last decade have provided a major incentive to develop alternative sources of energy. Concommitantly, governments have perceived increased reliability of supply through energy self-sufficiency, and for many countries this implies the need to establish an energy system based on renewable flows. Concern for renewable energy has also been promoted by a general awareness of the fact that fossil fuel reserves are limited.

Energy from biomass is an alternative that has attracted considerable attention in recent times (Hall et al., 1982; Inman and Salo, 1977; Love, 1980; Plotkin, 1980). In particular, there is renewed interest in wood as a source of energy (Evans, 1974; Grantham and Ellis, 1974; Intergroup Consulting Economists Ltd., 1978b; Overand and

Love, 1978). Although attention has focussed on the utilization of noncommercial standing timber and wood wastes, the potential for establishing energy plantations is also widely recognized (Anderson et al., 1983; Brown, 1976; Inman and Salo, 1977; Szego and Kemp, 1973; Rose, 1977).

This chapter begins with a brief discussion of the contribution of biomass to world energy supply. The major forest energy plantation projects throughout the world are then described. Estimates of energy supply potential from plantation forestry in Canada are presented and research and development initiatives are discussed. The hybrid poplar project in Eastern Ontario is examined in detail, focussing on the potential regional consequences of large-scale forest energy developments.

2.2 WORLD BIOMASS ENERGY USE

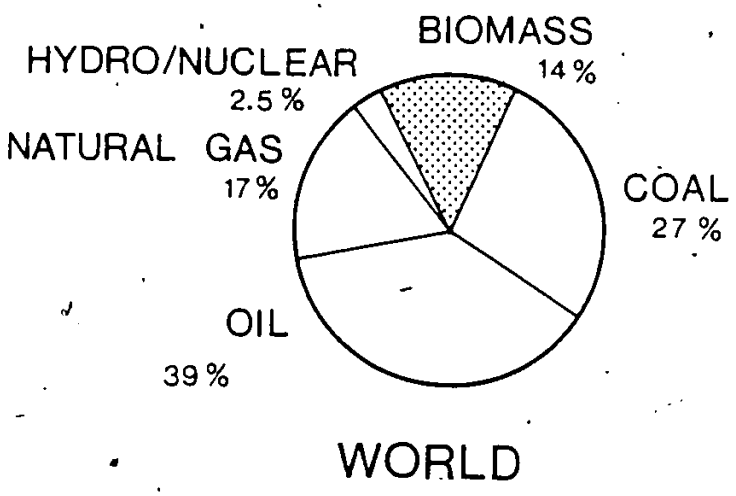
Biomass is defined as unfossilized biological material and in the energy context refers to such products as animal manure, aquatic plants, agricultural crops, forestry residues and trees. It is estimated that solar energy converted through photosynthesis and stored in the form of biomass each year is ten times greater than the world's energy consumption (Anderson and Zsuffa, 1983a; Hall and Moss, 1983). Total energy stored in biomass,

approximately 90 percent of which is in trees, is estimated to be equivalent to total proven fossil fuel reserves (Hall and Moss, 1983).

Approximately half the population of the world relies on biomass for its supply of energy and it is estimated that one seventh of the energy consumed globally is obtained from biomass (Hall et al., 1982). The role of biomass energy in developing nations is particularly significant (Figure 2.1), providing on average 43 percent of the energy used and accounting for more than 90 percent of the energy consumed in some countries (Chatterji, 1981; Hall et al., 1982).

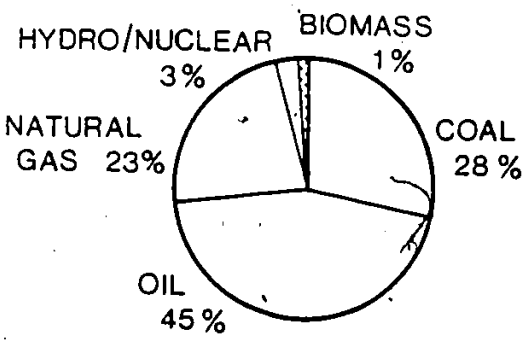
In developing countries, 90 percent of the total population currently relies on wood to provide 90 percent of the energy utilized (Chatterji, 1981). Hall and Moss (1983) estimate that in the rural areas of the developing world, one tonne of wood is consumed per person annually. The primary uses are for domestic cooking and heating, but wood is also used in industry and agriculture (Hall and Moss, 1983; Chatterji, 1981).

A serious consequence of the extensive use of wood as an energy source is deforestation. This has wide-ranging effects including the loss of topsoil, erosion, silting of dams and streams, increased flooding, and possible climatic changes (Hayes, 1981; Mathews and Siddiqi, 1981). As local wood resouces are depleted, social costs are incurred in



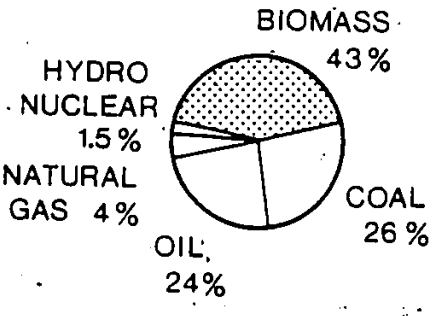
WORLD

(TOTAL = 300 × 10^9 GJ)



DEVELOPED COUNTRIES

(TOTAL = 208 × 10^9 GJ)



DEVELOPING WORLD

(TOTAL = 92 × 10^9 GJ)

FIGURE 2.1 GLOBAL DISTRIBUTION OF ENERGY USE (1978)
Source: Hall, Barnard and Moss, 1982

terms of higher monetary or labour costs associated with fuelwood collection (Hall and Moss, 1983).

Reforestation is a logical, if only partial, response to the "fuelwood crisis", but in developing countries replanting schemes are not well developed (Hall and Moss, 1983). Financial resources are often allocated to nuclear and fossil fuel developments, technologies considered by some to be ill-suited to the needs of people in the Third World (Hayes, 1981).

The contribution of biomass to energy supply in the developed nations has declined rapidly since the late 1800's. In North America, for example, fuelwood accounted for almost 90 percent of energy use in during the 1870's, but less than 5 percent of the energy used in North America today comes from biomass (Canada, House of Commons, 1981). The consumption of biomass energy in the developed world is estimated to be only 1 percent of the total (Figure 2.1). Recognizing that the various biomass energy alternatives potentially represent a large, domestically available and renewable energy source, many developed countries are exploring the opportunities for biomass to again contribute substantially to national energy supply.

Plantation forestry is one source of biomass energy that is regarded as having considerable potential, both for Third World countries and for developed nations (Anderson et al., 1983; Drysdale et al., 1983; Inman and Salo, 1977;

U.S. Department of Energy, 1978). Perceived advantages of forest energy plantations include (Anderson et al., 1983):

1. They represent a domestic source of energy, thus helping to maintain security of supply, and represent an advancement towards the objective of energy self-sufficiency;
2. Plantations are renewable;
3. Production systems are similar to those of cash crops and provide a rapid return on investment;
4. Production is at a local scale and benefits accrue primarily to the region;
5. The supply system is flexible in that plantations can easily be moved in response to changing spatial demand patterns;
6. Alternative end uses impart versatility to the tree crops;
7. Energy plantations are ecologically inoffensive; and
8. Society benefits through the improvement of regional economies and by creating employment opportunities.

The concept of forest energy plantations appears to have been first described by Szego and Kemp (1973). Subsequently, several countries have become actively engaged in research and development of forest energy

schemes. The following section further characterizes energy plantations and describes prominent projects throughout the world.

2.3 INTERNATIONAL PERSPECTIVES ON ENERGY PLANTATIONS

Forest energy plantations are considered to represent a viable alternative in regions where trees and wood residues are not locally available in sufficient quantities to supply biomass energy conversion facilities, but where land is available for the development of energy forests (Anderson et al., 1983). The existence of large areas of land not suited to food production but capable of supporting wood energy plantations implies that a substantial resource base for biomass production exists in many countries (Morgan et al., 1983).

Wood energy plantations are characterized as being comprised of genetically improved, intensively cultivated, closely spaced, broadleaved trees that are harvested repeatedly on cycles of ten years or less (Anderson et al., 1983). The primary concerns in establishing energy plantations relate to the bioecological basis (site, tree species, moisture and nutrient availability), genetic improvement of trees (hybridization and cloning), and cultural practices, namely site preparation, weed control, fertilization, and irrigation (Anderson et al., 1983).

The ability of hardwood trees to sprout from coppices leads to reduced replanting requirements and, accordingly, hardwoods are favoured over conifers for energy plantations (Sajdak et al., 1981). In addition, the rapid growth characteristics of hardwood sprouts generally defines these trees as being better suited for energy plantations. Sajdak et al. (1981) note, however, that due to the site specific nature of plantations, there are instances when conifers may be more desirable.

Research has been particularly active since the late 1970's and Bente (1981) lists 55 wood energy plantation projects operating in 14 countries. International cooperation in forest energy research plays an important role in information dissemination. The International Union of Forest Research Organizations, the International Poplar Commission and the Forest Energy Program of the International Energy Agency (IEA/FE) have greatly facilitated international interaction in forest energy research (Drysdale et al., 1983).

The most active of these agencies with respect to forest energy plantations is the IEA/FE. The agreement was formed in 1978 by Belgium, Canada, Ireland, Sweden and the United States, with the intention of improving the interface between energy and forestry (Morgan et al., 1983). Research activities were initially coordinated through four Planning Groups:

a) Systems modelling and analysis;

b) Biomass growth and production;

c) Mechanization of production systems; and

d) Conversion of biomass to energy.

In 1982, these were developed into "Programme Groups" and systems modelling and analysis were integrated into each of the other groups. The original member nations have subsequently been joined by Austria, Denmark, Finland, New Zealand, Norway, Switzerland and the United Kingdom (Morgan et al., 1983).

The relatively recent origin of forest energy developments has afforded little opportunity for countries to collate, coordinate and summarize information on the various aspects of plantation projects. To provide an overview of the status, characteristics, location and extent of development of forest energy plantations throughout the world, an international survey was conducted. Sources of information were diverse, but previous surveys were the single most important data source (Bente, 1981; Dahl and Lundberg, 1981; Drysdale et al., 1983; Zsuffa, 1982). Personal communications, conference papers and research reports were used to fill in the details. The results of this survey are presented in Table 2.1.

Despite the considerable number of countries involved, very few have moved beyond the research stage of

TABLE 2.1

FOREST ENERGY PLANTATIONS:
CURRENT STATUS, PRODUCTION SYSTEMS, AND END USES

	BRAZIL	CANADA	FINLAND	FRANCE
Stage of Development	Doubling of reforested areas is planned by the year 2000. Aim to replace petroleum derivatives almost entirely with alcohol produced from biomass.	Plans not yet established for energy plantations, but research, development and demonstration and modest scale planting is in place and very active.	Biomass production in energy planations is being considered. 39.5 ha of research plantations already established, further 60 ha to be developed in 1983-88.	Conducting experiments on breeding and silviculture of species for fuel production.
Type of Trees Used	Pine and eucalyptus plantations.	Concentrates on poplar with willow and alder research in early stages.	Willow.	Poplar, aspen, alder, larch, eucalyptus.
Management System	Spacing 1 m x 1.5 m Rotation 7 - 10 years Yields 12 odt/ha/a	Short rotation Spacing 3 m x 3 m Rotation 7 years Yields 5-7 odt/ha/a Mini rotation Spacing 0.3 m x 0.9 m Rotation 1 - 5 years Yields 15 odt/ha/a	Mini rotation Density > 20000 plants/ha Rotation 1-5 years Yields 10 odt/ha/a Short rotation Density 10000-20000 plants/ha/a Rotation 5-15 years Yields 4.5 odt/ha/a	Density 2000-4000 plants/ha Rotation 6 years Yields 12 odt/ha/a
End Use	Charcoal and alcohol.	Co-generation of steam and electricity, direct combustion, methanol production.	District heating.	Methanol production.
Funding Source	Program backed by institutional and university research and Ministries of Agriculture, Industry and Commerce, Mines and Energy, and Planning.	Canadian Forestry Service (Energy from the Forest Program), Federal Department of Regional Economic Expansion, Provincial Ministries of Treasury and Economics, Intergovernmental Affairs, and Natural Resources.	Not available	European Community, French Department of Agriculture, French Solar Energy Committee.

Source: Cocklin et al., 1985.

Table 2.1 continued

	IRELAND	ITALY	NETHERLANDS	NEW ZEALAND
Stage of Development	340 ha of energy plantations already established and a further 280 ha planned for 1983-88.	Pilot plantations have been established across Italy. Trials dealing with silvicultural, harvesting and technological aspects.	Feasibility study of short rotation forestry began in 1978.	Preparing for the production of liquid fuels from wood but does not expect significant use of biomass before 2000.
Type of Trees Used	Salix aquatica gigantia, five poplar clones and three alder species.	Oak (Quercus cerris, Q. tarnetto, Q. pubescens).	Poplar.	Radiata pine, trials with willow and poplar.
Management System	Spacing 0.3 m x 1 m to 0.6 x 1 m Rotation 3-5 years Yields 15 odt/ha/a	Still under research.	Density 1600-2500 plants/ha Rotation 4-7 years Yields 14.4 odt/ha/a	Spacing 0.3 m x 0.3 m to 1.2 m x 1.2 m Rotation 1-2 years Yields 8.9 to 30.8 odt/ha/a
End Use	Electrical generation.	Not available.	Thermochemical biomass gasification and methanol production.	Liquid fuels (methanol and ethanol)
Funding Source	European Community, Dublin State Forest Service, National Institute for Agricultural Research, Department of Forestry and Fisheries, Irish Peat Development Board, and universities.	National Agency for Pulp and Paper, Ministry for Agriculture and Forestry, and Commission of European Communities.	European Economic Commission.	National Plant Material Centre.

Table 2.1 continued

	PHILIPPINES	SWEDEN	UNITED KINGDOM	UNITED STATES
Stage of Development	A four year development scheme is being implemented to establish 50 tree plantations in the country to fuel dendrothermal power plants.	Two major short rotation pilot farms have been established. 110 ha on abandoned farmland and 85 ha on unproductive peatland.	Program began in 1979 to examine the feasibility of short rotation forestry and forest biomass for energy in the U.K.	Demonstration plantations established on about 1500 ha in southeast, northeast and north central regions.
Type of Trees Used	Ipil - ipil.	Primarily willow.	Birch, sycamore, alder, Hybrid larch. Nothofagus, Douglas fir, Corsican pine, Scots pine, Western hemlock, Sitka spruce.	Eucalyptus, leucaena leucocephala, cottonwood, Sycamore, black alder, Loblolly pine, Maple, Poplar, black locust.
Management System	Spacing 0.3 m x 0.3 m to 3 m x 3 m Rotation 4-6 years Yields 5-25 odt/ha/a	Spacing 0.75 m x 1.25 m Rotation 2-3 years Yields 12-20 odt/ha/a	Hardwood coppice Density 2500-10000 plants/ha Rotation 2-6 years Yields 15-20 odt/ha/a Single stem plantation Rotation 12-20 years Yields 8-12 odt/ha/a	Varies with species and sites, e.g. Spacing 0.3 m x 0.3 m to 3 m x 3 m Rotation 2-7 years Yields 6-17 odt/ha/a
End Use	Dendrothermal power plant (3MW).	District heating.	Methanol production.	Ethanol, electricity generation, direct combustion, low Btu gasification.
Funding Source	Government supports the program by loans.	National Swedish Board for Energy Source Development.	United Kingdom Department of Energy, European Economic Community.	Department of Energy, U.S. Forest Service, individual states, universities and the private sector.

development. Only Brazil, Ireland and the Philippines presently report commercial scale operations. In several other nations, however, research is at an advanced level and it is expected that the commercial production of energy from plantation forests will commence within the next few years. Amongst these are Canada, Finland, Sweden and the United States.

Species of trees used in energy plantations differ throughout the world. Most countries, however, have chosen a fast-growing hardwood. The most commonly used species are poplar (Canada, Ireland, Netherlands, U.S.), eucalyptus (Brazil, France, U.S.) and willow (Finland, New Zealand, Sweden). Experiments have also been conducted in some countries with softwoods, specifically pine (Brazil, New Zealand, U.K., U.S.).

Although it was not possible to obtain complete information on management practices, it is clear from Table 2.1 that production systems vary considerably. Trees are planted either as seedlings or cuttings and in spacings that range from 0.3m x 0.3m to 3.0m x 3.0m. Planting densities reported range from 1,000 plants per hectare to more than 35,000 plants per hectare. Rotations vary from 1 to 20 years and recorded plantation yields are from 4 to 30 oven dry tonnes (ODts) of biomass per hectare annually.

Anticipated conversion processes are selected according to the specific needs of the nation or region.

The methods of conversion currently under development in the surveyed nations are electricity generation (Canada, Ireland, Philippines, U.S.), the production of alcohol fuels (Brazil, Canada, New Zealand, U.K., U.S.), pyrolysis to produce charcoal (Brazil), district heating (Finland, Sweden), and direct combustion for institutional, commercial ~~and~~ industrial heating (Canada, U.S.).

Financial support for energy plantation research is generally provided by the respective governments. In Brazil, Ireland and the U.S., however, extensive additional funding is provided by universities and the private sector.

Countries that rely heavily on imported fuels have been most active in developing alternative energy sources, including forest biomass, and this is reflected in Table 2.1. For these nations, the need to reduce energy costs has been an important incentive to developing domestic, renewable resources.

2.4 FOREST BIOMASS ENERGY IN CANADA

Canada is one of only a few developed countries that are net exporters of energy (Energy, Mines and Resources, 1980). Despite this, the nation is heavily dependent on crude oil imports (Canada, House of Commons, 1981). Recognizing the inevitable finitude of fossil fuel reserves and with a stated commitment to reducing the dependency on

imported oil (Energy, Mines and Resouces, 1980), increasing emphasis has been placed on the development of renewable energy resources.

Federal expenditures on renewable energy research and development have increased markedly since the early 1970's (Figure 2.2). Nuclear energy research continues to absorb the large majority of federal funds, but the renewable sector has made significant gains, now accounting for almost 13 percent of the total federal energy research and development budget. The greater recognition of renewable resources is also reflected in the establishment of the Renewable Energy and Conservation Branch of Energy, Mines and Resources, and the appointment of the Special Committee of the House of Commons on Alternative Energy and Oil Substitution.

Among the various renewable energy sources that exist, biomass, particularly from forests, is recognized as an alternative with considerable potential in Canada (Canada, House of Commons, 1980; Intergroup Consulting Economists Ltd., 1978b; Love, 1980; Overand and Love, 1978). The federal government has initiated several research programs devoted explicitly to the promotion of biomass energy. The Energy from Forests (ENFOR) project was established in 1978/79 with the mandate to provide funding for research and development by the private sector and provincial governments on biomass technology. The objective

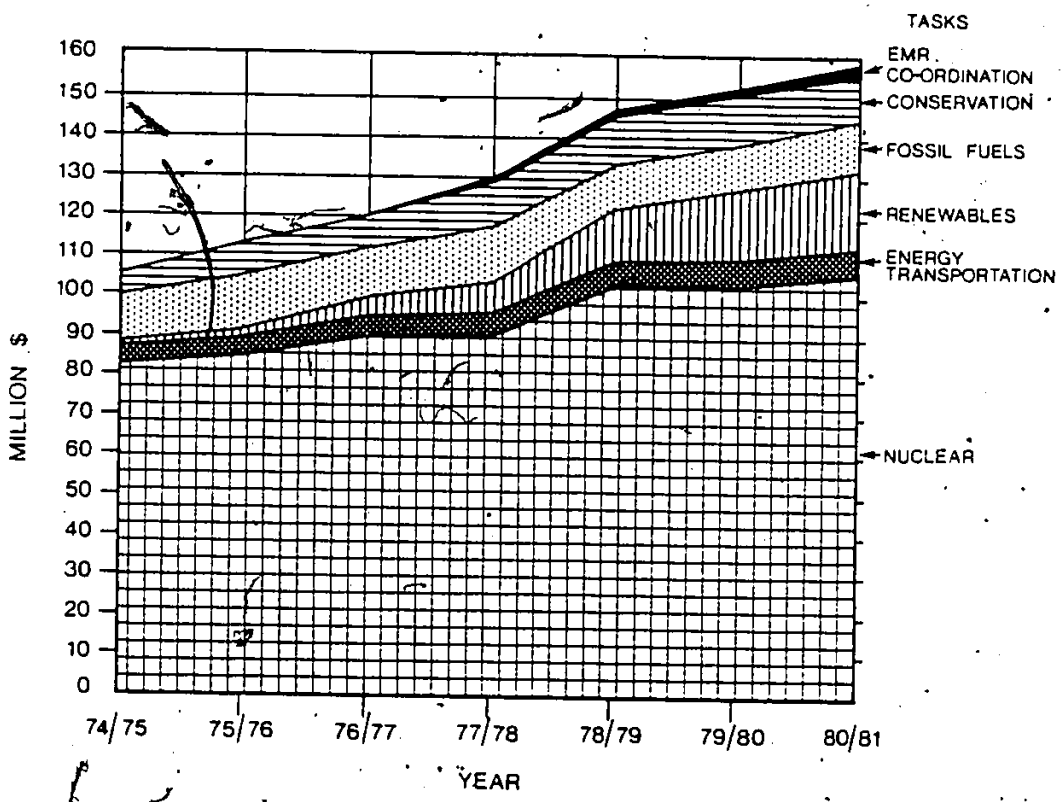


FIGURE 2.2: Federal Energy R/D Allotments

SOURCE: Cockshutt, 1980

was to provide a technological basis for the substitution of biomass for fossil fuels to the extent of 8 percent of Canada's primary energy demand by 1985 (Love, 1980). ENFOR is coordinated by the Canadian Forestry Sevice of Environment Canada and was granted an operating budget of $29.9 million for the 6 year project duration.

The Forest Industry Renewable Energy program (FIRE) was also initiated in 1978/79, with the objective to provide incentives for industry to utilize waste forest biomass as a source of energy (Love, 1980). This project is coordinated through the Conservation and Renewable Energy Branch of Energy, Mines and Resources and was given a budget of $103 million for a 6 year period. A related program is the Biomass Energy Loan Guarantees (BELG), which is coordinated by the FIRE Secretariat and which has similar objectives to those of the FIRE program.

Several surveys of forest biomass energy potential in Canada and the provinces have been undertaken (see, for example, Love, 1980; Overand and Love, 1978; Peat, Marwick and Partners, 1981a). The most extensive survey is that by Intergroup Consulting Economists Ltd. (1978b). Forest biomass availability was estimated for each province at alternative supply cost levels for the period 1985-2025. Sources of forest biomass considered were residues from conventional forestry operations, harvests from natural stands, and harvests from managed plantations.

Estimates of potential supply fom biomass plantations in the year 2005 at price levels of $33/ODt and $44/ODt are presented in Table 2.2. At a price level of $33/ODt, the contribution of biomass plantations to total estimated forest biomass supply is approximately 23 percent; at $44/ODt the contribution to total potential supply is less at 13 percent. Assuming an energy content of 20 GJ/ODt (Love, 1980), the estimates of annual plantation biomass supply potential in Canada at $33 and $44 price levels are 318 and 400 PJ, respectively (total annual energy consumption in Canada was 7,000 PJ in 1980).

2.5 HYBRID POPLAR IN EASTERN ONTARIO

The hybrid poplar project in Eastern Ontario was initiated in the late 1960's in response to the need to provide wood fibre to the local pulp and paper industry (Zsuffa, 1982). As work progressed, it became evident that poplar biomass has potential for a variety of end uses, including energy production, as an animal feed, and for chemical feedstock. Recently, research has focussed on the optimization of plant growth to achieve maximally efficient production of energy (Anderson and Zsuffa, 1983a). Proposed energy end uses for poplar biomass in Ontario include direct combustion for institutional heating, co-generation of process steam and electricity, and production of

TABLE 2.2

ESTIMATED SUPPLY OF BIOMASS FROM ENERGY PLANTATIONS IN CANADA, 2005.

Province	Biomass Supply (millions ODt)	
	Supply Price ($/ODt)	
	33.00	44.00
British Columbia	-	-
Alberta	2.3	4.5
Saskatchewan	1.8	1.8
Manitoba	1.8	1.8
Ontario	4.5	4.5
Quebec	1.8	3.6
New Brunswick	1.8	1.8
Nova Scotia	1.8	1.8
Newfoundland	-	-
CANADA	15.9	20.0

Source: Intergroup Consulting Economists Ltd., 1978.

methanol for use as a transport fuel (Peat, Marwick and Partners, 1981b).

Forest geneticists and research foresters at the Ministry of Natural Resources research stations in Maple and Brockville, Ontario, have been responsible for the major technological advancements in hybridization and plantation management techniques that will facilitate the commercial development of forest energy plantations in Ontario. As a result of extensive laboratory and field tests, it is now possible to match poplar clones to local sites in order to achieve consistently high yields of biomass (Barkley et al., 1983). Moreover, clones may be selected according to their suitability for specific end uses. More than 130 hybrid poplar clones have been developed and evaluated according to productivity and energy content, as well as other desirable characteristics such as pest resistance and rooting (Anderson and Zsuffa, 1983a).

Combinations of rotation length and planting density define alternative management systems. Although many possible combinations exist, three management systems are employed in Eastern Ontario (Evers et al., 1983). The 35K system has a density of approximately 35,000 plants per hectare, spaced 1.0m x 1.0m, and has a rotation length of 2 years. System 4K involves a rotation length of 5 years and a planting density of 4,000 plants per hectare. The plant

spacing is approximately 1.5m x 1.5m. In a low density production system, 1K, the density of planting is 1,000 per hectare, with a spacing of 3.0m x 3.0m, and for which the rotation length ranges from 8 to 12 years.

Relative economic deprivation and large areas of underutilized land in Eastern Ontario are important considerations in defining the region as appropriate for the development of poplar plantations. Forest energy plantations, it is widely believed, may contribute significantly to regional economic development (Anderson et al., 1983; Peat, Marwick and Partners, 1982; Wayman, 1978). Promotion of hybrid poplar plantations, however, is contingent upon the ability to satisfy a variety of related objectives. These relate to economic efficiency in both the production of biomass and energy conversion, net energy gains, and quality of the environment. The various concerns with respect to hybrid poplar production and utilization are described in greater detail below.

2.5.1 Economic Efficiency

Concerns for economic efficiency relate to both the biomass production and energy conversion phases of forest energy developments. For landowners to participate in the production of biomass, they must be reasonably assured of a positive return to their investment. Several studies have

been undertaken to estimate the economic feasibility of forest energy production systems (Bowerson and Ward, 1976; Inman and Salo, 1977; Neenan and Lyons, 1981; Pfeiffer, 1978; Rose, 1977). The considerable sensitivity of biomass production costs to such factors as site, rotation length, productivity levels and management practices suggests that it is unwise to attempt general statements with respect to the economic feasibility of forest energy plantations. Most studies suggest, however, that under favourable conditions satisfactory returns on investment can be achieved.

Input costs include land rent, site preparation, planting, fertilization, weed control, and harvesting. The significance of each of these in terms of total costs varies from one study to another. Irrigation and fertilization were estimated to account for up to 40 percent of total cost of production at selected sites in the U.S. (Inman and Salo, 1977). Studies in Canada by Peat, Marwick and Partners (1981) and Intergroup Consulting Economists Ltd. (1982) suggest that harvesting costs are the most significant (greater than 50 percent of total costs in each case).

With the capability to allocate resources to biomass production, a resource assessment methodology can be utilized to identify the extent to which goals relating to economic efficiency in biomass production can be achieved, given assumed resource limitations and other development

priorities. Sensitivity of goals achievement to changes in assumed input costs, market prices, yields, management practices and the relative importance assigned to the economic efficiency of production is information that may be of value in assessing resource development options.

The success of biomass energy developments will also depend fundamentally on the ability of investors in the conversion processes to obtain a satisfactory return, while producing energy at a price that is competitive with energy derived from conventional sources. In Canada and elsewhere, several attempts have been made to assess the economic feasibility of using biomass in various energy conversion processes (Bliss and Blake, 1977; Moran and Nautiyal, 1981; Pfeiffer, 1978; Rose, 1975; Seckington, 1982).

Results of studies in Canada have led to inconsistent conclusions regarding the economic viability of wood-based energy systems. Evans (1974), Moran and Nautiyal (1981) and Sekington (1982) do not foresee such energy conversion systems as being economic for many years to come. On the other hand, studies by Acres Shawnigan Ltd. (1979), Dick Consulting Ltd. (1981), Intergroup Consulting Economists Ltd. (1978), Pfeiffer (1978) and Peat, Marwick and Partners (1981b) indicate that wood-based energy systems may currently be economically feasible, or will become so within the next few years.

Co-generation of electricity, methanol production

and institutional heating, as noted previously, are energy end uses for which biomass could be used as a feedstock. Concerns exist for the economic viability of each of these potential end uses. The economic efficiency of each of the end uses in relation to the others is also of interest. A resource assessment methodology might be employed to identify resource allocations (biomass to energy conversion processes) that best satisfy goals relating to economic efficiency in conversion. The methodology should also have the capability to assess the effects of biomass prices, the quantity of biomass available, other input costs, plant size and energy prices on the achievement of goals relating to economic efficiency.

2.5.2 Energy Efficiency

Concerns for energy efficiency, particularly in relation to energy projects have become more pronounced in the last decade. In the United States, net energy analyses are recognized as a fundamental aspect of researching new energy sources, as stated in Section 5 of the Non-Nuclear Energy Reserch and Development Act of 1974. A similar concern exists in Canada, although net energy analyses are not required by legislation.

Research scientists have devoted considerable attention to the maximization of energy yield from hybrid

poplar plantations (Anderson and Zsuffa, 1983a; Sastry and Anderson, 1980). A complete energy analysis of forest energy developments in Eastern Ontario, however, has not been conducted.

Results obtained from studies in the United States suggest that plantation forests are not energy-intensive operations. Inman and Salo (1977) have estimated that the energy stored in forest biomass ranges from 10 to 15 times the amount utilized in production. Positive net energy balances were also estimated in an evaluation of forest biomass as a fuel source for a 100MW electric generating facility in Pennsylvania (Blankenhorn et al., 1978). The most substantial energy inputs are fertilizer, transportation, harvesting and wood drying.

On the basis of these results, it is expected that, in general, energy plantations would not be excluded on the basis of unfavourable energy budgets. Questions relate to the energy yield when resources for production and conversion of biomass are devoted to alternative end uses. Sensitivity of plantation energy budgets to transportation distances, alternative harvesting techniques, and input substitution demands further attention. Questions also relate to the impact on energy efficiency of changes in the assumed energy conversion processes. These questions, and the identification of conflicts between energy efficiency goals and other development priorities could be evaluated

via a resource assessment methodology.

2.5.3 Regional Development

In Ontario, the Eastern region is generally recognized as being economically underdeveloped. Personal incomes and employment levels are lower than the provincial average, the percent share of provincial population has been declining over the past two decades, and the level of social services is low relative to the provincial average (Wayman, 1978). Agriculture is the dominant economic activity of the region, but in recent times there have been major retrenchments in the amount of land devoted to agriculture, and the prospects for economically viable farming are considered to be limited (Beattie et al., 1981).

A recent study has indicated that wood-based energy systems are labour intensive relative to conventional energy sources (Office of Technology Assessment, 1980). Contributions to the Eastern Ontario region in terms of employment and income generation are expected as a result of plantation forestry developments (Peat, Marwick and Partners, 1981a; Wayman, 1978). More than one half-million hectares of land are estimated to be available (Peat, Marwick and Partners, 1981a; Wayman, 1978), and energy plantations could bring into productive use a large

proportion of the underutilized resource. The production of biomass and energy conversion processes are expected increase regional labour participation and regional income, both directly through the energy development and by inducing expansion in other regional sectors.

Different allocations of resources to biomass production and energy conversion may imply very different results in terms of these regional development effects. The identification of resource allocations which best satisfy regional development goals may be of importance in resource development decisions. The conflict between regional development concerns and other goals relating to energy forestry projects is also potentially of interest. Additionally, the effects on regional development indicators of changes to the assumed production and conversion practices should be investigated.

2.5.4 Environmental Quality

Forest energy projects are often regarded as not being disruptive to the environment, and in some respects are considered to be environmentally benign (Wayman, 1978). Compared to most fossil fuel sources, forest biomass is less environmentally damaging. Negative environmental impacts will result, however.

The production of biomass involves management

practices very similar to those employed in conventional agriculture, and the environmental effects are much the same (Zsuffa and Morgan, 1983). Specifically, the rapid growth characteristics of genetically improved trees and whole tree harvesting exerts a heavy drain on soil nutrients (Miller, 1983). To achieve sustained productivity, it is necessary to replace nutrients with fertilizer (Anderson et al., 1983; Miller, 1983). Surface runoff may carry fertilizer to natural water bodies where increased rates of eutrophication may occur (U.S. Department of Energy, 1978). Similarly, pesticides and herbicidies may also be transported to water bodies, killing aquatic flora and fauna. Sediment from soil erosion is the primary pollutant affecting water quality and cropland contributes approximately 50 percent to the total sediment loading in lakes and streams (Conservation Foundation, 1982; Meister et al., 1976). The U.S. Department of Energy (1978) suggests that large energy plantations may contribute sediment loads that are at least equal to those from agriculture. Concerns also relate to competition for land and water resources, although this is not perceived to be a major problem in Eastern Ontario.

Careful management practices in agriculture minimize environmental disruption, and similar management techniques could be applied to forest energy plantations. Plotkin (1980), for example, recommends reduced tillage practices,

soil analysis to minimize fertilizer applications, and plant breeding to reduce susceptibility to pests. Zsuffa and Morgan (1983) suggest that recycling of tree foliage and the return of ash to the soil will assist in maintaining the nutrient status of the soil. Selection of the optimal harvesting time and the development of plantations on flat ground will help in minimizing leaching and soil deterioration through erosion (Zsuffa and Morgan, 1983).

Emissions of air and water pollutants will result from biomass conversion processes. Combustion of biomass, either for heating or in wood-fired thermal plants, releases into the atmosphere particulate matter and chemical pollutants, including CO_2, CO, HCl and NO. (Canada, Department of the Environment, 1982). The production of methanol may also produce emissions of CO and CO_2, and liquid and gaseous hydrocarbons. Other chemical residues may be deposited in adjacent water bodies (Canada, Department of the Environment, 1982). In general, the emissions of these pollutants are considered to be considerably less than from fossil fuel plants, and opportunities exist to control emission levels (Canada, Department of the Environment, 1982; U.S. Department of Energy, 1978; Wayman, 1978).

Maintenance of a high standard of environmental quality may be an important priority. For this research,

the relevant questions relate to how resources can be allocated to energy plantations and conversion processes in order to minimize environmental stress. In addition, the potential conflicts between environmental concerns and other development priorities should be identified. The effects upon environmental indicators of alternative assumptions with respect to production relationships and resource constraints might also be evaluated using the resource assessment methodology.

2.6 SUMMARY

Prompted by the oil crises of the 1970's, energy plantation projects have been attributed considerable importance in the energy programs of several nations. Brazil, Ireland and the Philippines have already incorporated forest energy plantations into their energy supply systems. Many other countries, including Canada, have initiated research and development programs devoted to the eventual establishment of commercial scale forest energy plantations.

From the discussion above it is clear that forest energy developments may have significant regional consequences in Eastern Ontario. Concerns relate particularly to economic efficiency in biomass production and energy conversion, net energy gains, regional

employment and income generation, and environmental quality. Important questions relate to how land and other resources could be allocated to biomass production and energy conversion in order to best satisfy goals relating to these various concerns. This demands a thorough understanding of the trade-offs that exist between development goals and of the sensitivity of goals achievement to the assumed economic, environmental, social and political conditions that exist within the region. Analysis of this type has been referred to here as resource assessment. In the presence of multiple goals, resource allocation decisions are extremely complex and necessitate the implementation of methodological frameworks that adequately reflect the integrated nature of development problems. The following two chapters review several prominent methodological frameworks, focussing on their capabilities to address those questions that are central to resource assessment analyses.

NOTES

1. In reference to the case study, the term economic efficiency is consistent with the standard economic term "net private benefits". For an explicit mathematical definition of economic efficiency as it is used in this context, see equation 5.6.

CHAPTER 3

METHODOLOGIES FOR RESOURCE ASSESSMENT 1: PLAN EVALUATION AND IMPACT ASSESSMENT

3.1 INTRODUCTION

The allocation of environmental stocks to end uses, such that societal welfare is most improved, is the fundamental objective in resource management. Resource allocation decisions have traditionally been dictated by concerns for economic and technical efficiency. The increasing recognition of social, environmental, and energy concerns, which together with economic concerns define societal welfare, means that resource assessments must be performed in relation to multiple goals. As a consequence, major challenges have emerged with respect to developing and implementing analytical procedures which adequately represent the integrated nature of resource development problems.

The purpose of this chapter is to review prominent methodological frameworks, in terms of their suitability for the type of resource assessment analysis proposed herein. The methods of this chapter have been grouped into

two categories: 1. Plan evaluation methods; 2. Methods for impact assessment. In Chapter 4, linear programming methods are reviewed. Arguments in support of analysis that explicitly accounts for multiple goals in resource development are expanded upon in the next section, prior to the review of methods.

3.2 METHODOLOGICAL ISSUES IN RESOURCE MANAGEMENT

Within research disciplines, there is a tendency to focus on a limited set of interdependencies. Economists, for example, abstract from nature and analyze in detail only the interdependencies between man and commodities. Environmental factors are acknowledged only to the extent that they influence market prices. That man and his system of production and exchange function within and as a part of the ecosystem is not explicitly recognized in traditional economic theory. Similarly, the ecologist abstracts from the human economy in order to study natural interdependencies in detail.

Partial analyses of this kind are extremely useful in that they have allowed for the development of a very detailed level of understanding of particular sets of interdependencies. In certain contexts, however, including natural resource planning, this approach is inadequate, since the issues and goals are typically multidimensional.

Consequently, there has been an increasing demand for the comprehensive, integrated evaluation of the impacts of man's activities. The need to develop analytical techniques capable of synthesizing the vast array of information relevant to planning assignments and presenting it in such a way as to facilitate decision making is now widely recognized (Lakshmanan and Nijkamp, 1980; Lonergan, 1981; McAllister, 1982).

The demands for comprehensive methodologies are well-founded and have not been entirely ignored by analysts. For comprehensive evaluation, Nijkamp (1980) stresses the integration of the social, economic, and environmental "subsystems". There are two important prerequisites for analysis: 1. That a satisfactory degree of disaggregation be maintained so that the various subsystems are visible; and 2. That the interactions between the subsystems be satisfactorily described. Frequently, these conditions are not satisfied in project evaluations. This might be attributed to what McAllister has termed the "evaluation dilemma": "One of the central problems in any evaluation can be characterized by what I have referred to as the "evaluation dilemma", in which the force for detail and the force for holism oppose one another" (McAllister, 1982: 184).

Additionally, with an apparent preference amongst decision makers for analysts to provide summary measures of

impact, there has been a distinct tendency towards the application of methods that are designed to synthesize the various impacts and yield a summary measure of project impact. Problems in calculating summary measures may be encountered, however, due to the incompatibility of data which measure impacts in the social, economic and environmental subsystems. This is the valuation problem. Methods are often appropriate for the evaluation of either economic, or social or environmental effects, and the majority developed to date have emphasized economic concerns. Efforts to attain greater breadth of analysis have often resulted in the application of a method to evaluate impacts for which it is inherently unsuited.

Three approaches to the specification of comprehensive methodologies have been tried:

1. The adoption of methods which rely on the specification of impacts in single metric. Claims for comprehensiveness refer to the supposed universality of the metric employed.
2. A "multi-method" approach in which the estimation and/or evaluation of impacts in each of the subsystems is conducted using methods appropriate to the subsystem. The final synthesis is left to the decision makers.
3. The application of methods that are capable of processing multiple metric information.

In the review of this chapter and that of Chapter 4, further attention is given to each of these alternatives. A preference is held for the third option and this is reflected in the adoption in this research of a multiobjective programming system.

3.3 PLAN EVALUATION METHODS

The methods described in this section have been designed to structure and analyze information on proposed alternatives and indicate which is the most desirable plan according to a specified decision rule. A common characteristic of these methods is that alternative plans must be specified prior to the analysis, the method then providing a framework within which to evaluate the alternatives listed. A further characteristic of some of the methods discussed is that items are quantified in a single metric. Frequently, proponents of these particular methods have argued that the frameworks are suitable for comprehensive evaluation, invoking considerable debate as to the ecumenicism of the value measures employed. The methods reviewed in this section are cost-benefit analysis, planning balance sheet analysis, the goals achievement matrix, and energy analysis.

3.3.1 Cost-Benefit Analysis

Cost-benefit analysis (CBA) was developed through the 1930's and 1940's for the evaluation of water resource project designs (McKean, 1958). Since then, CBA has found extensive application in transport planning, education, port investment, urban planning, pollution control, recreation, military defence, and agricultural land-use planning (Peters, 1970). CBA is the most extensively used formal plan evaluation method and the appropriate procedures have been widely documented (see, for example, Sugden and Williams, 1978; Mishan, 1976). In essence, CBA involves the application of the rules of profit-maximizing investment behaviour of firms to the circumstances in which governments operate (Hill, 1973). Assessments proceed by identifying, quantifying (typically in monetary terms), and summing all costs and benefits of a specific project and selecting between alternatives on the basis of that which yields the greatest economic benefit. Economic efficiency, then, is promoted as the principal criterion in choosing between alternative courses of action.

In ascribing such prominence to economic efficiency, one of the most significant difficulties to emerge is the valuation of impacts that are not amenable to pecuniary measurement. Under such circumstances, one of two procedures is usually adopted. One approach is to exclude

items that are not quantifiable in monetary terms from the formal analysis, and simply draw attention to their existence in descriptive paragraphs appended to the analysis (Lichfield et al., 1975). It is then left to the decision maker as to how this information should be assessed. Whether non-quantified information receives appropriate recognition is a matter of considerable doubt (McAllister, 1982).

The second approach to accounting for non-market items that has been adopted is to impute dollar values. In dealing with market commodities, the general approach to quantification is to identify the willingness-to-pay for goods and services. This can usually be estimated using prices from market demand curves (McAllister, 1982). One criticism of this approach is that concerns for equity are overlooked, since the willingness-to-pay criterion takes no account of ability to pay. Notwithstanding this criticism, cost-benefit analysts have attempted to estimate demand curves for items not usually traded in the market place: wildlife, aesthetics, recreation benefits, human life, and quality of the environment, for example. Perhaps the most successful example is the effort of Clawson and Knetsch (1966) to value outdoor recreation sites on the basis of travel costs expended by visitors to the sites.

Attempts to quantify in monetary terms items that are not traded in the market has come under severe

criticism, though, particularly from those adhering closely to environmental and humanist values. The basis for this criticism is well expressed by McAllister (1982: 142-143):

> There is serious doubt that dollar values can or should be placed on many types of environmental, social and political impacts. These impacts relate to issues and problems that people do not equate with money.

Hence;

> ...some of its serious limitations are inherent to its fallacious premise that all human values can be adequately represented by money...The inevitable conclusion is that CBA is not and cannot become a completely comprehensive evaluation method.

Restricted to an evaluation of the economic impacts of a project, CBA represents a valid approach to estimating the net benefits of the given alternatives. Extending the analysis to non-market items requires that monetary values be ascribed to social and environmental assets and, in general, this demands the adoption of untenable assumptions. Attributing dollar values to environmental, social and human concerns obscures the issues that are involved and may result in inappropriate valuations, given the full range of societal objectives.

CBA requires that alternative plans be specified in advance of the analysis. The method then provides a framework within which to evaluate the specified alternatives, according to their economic efficiency. This procedure might insure that the alternative selected is the most suitable (according to the stated criteria), but there

is no guarantee that there are not other plans that would better satisfy the conditions. In fact, any number of unspecified alternatives may be substantially better than all of those proferred (Houghton, 1974). Thus, CBA does not provide a mechanism by which to satisfactorily address the first question posed, which refers to the allocation of resources in a manner that best satisfies a set of stated conditions. Given also the inability of the technique to affectively account for non-economic concerns, resource development alternatives cannot be compared when multiple goals or objectives exist. CBA does not, therefore, provide a satisfactory approach to addressing those questions that are considered fundamental to resource assessment.

3.3.2 The Planning Balance Sheet

The planning balance sheet (PBS) was developed by Lichfield (1971) as an alternative to cost-benefit analysis in evaluating urban and regional development proposals. Lichfield cites a concern for the explicit recognition of equity concerns as being a primary reason for the development of PBS (Lichfield et al., 1975). He asserts that traditional CBA does not adequately account for the incidence of costs and benefits on the groups affected, whereas PBS allows the analyst to set out the items of cost

and benefit against each group who will experience the consequences of a particular project, and to trace the ultimate incidence of gains and losses (Lichfield et al., 1975).

The analysis begins by enumerating those who are involved in the establishment and running of the project. These actors are referred to as the producers/operators and are listed vertically in the balance sheet (Table 3.1). Each of the producers/operators is then paired with the appropriate groups who will be "consuming" the goods and services. "Consuming" here includes both market transactions as well as notional transactions - public goods and externalities. Because of the difficulty in quantifying the latter, these may simply be represented by a positive or negative symbol. Although some of the information may be summarized, no single index is calculated, and the decision maker is left to make the final synthesis as a mental process.

There are three major limitations to the PBS method (McAllister, 1982). First, although intangible impacts are incorporated within the matrix, they are not quantified and may be at a disadvantage relative to those impacts valued in monetary terms when it comes to the final evaluation. Second, impacts are organized around transactions and this may be to the disadvantage of minority groups which do not represent a large, unified consumer group. Finally, impacts

TABLE 3.1

THE PLANNING BALANCE SHEET

Producer	Plan A		Plan B		Consumer	Plan A		Plan B	
	Benefit	Cost	Benefit	Cost		Benefit	Cost	Benefit	Cost
1					2				
3					4				
5					6				
7					8				

Source: McAllister, 1982.

such as pollution, which may have only minor effects on individual groups, may not be included. In aggregate, however, the impact may be severe and warrant explicit consideration.

More important in terms of this research, is the fact that PBS, like CBA, does not provide an adequate framework within which to compare plans relative to multiple goals or objectives. Although the framework permits the comparison of alternative plans in terms of more than one criterion, the evaluation criteria are not expressed in the form of planning goals or objectives. Hence, the contribution of each plan to the goals of the planning exercise remain undetermined as do the trade-offs between goals when one plan is compared with others. In common with CBA, the PBS approach also demands that alternative development plans be specified prior to the analysis.

3.3.3 Goals Achievement Matrix

Dissatisfaction with the theoretical notions underlying CBA and PBS led Hill (1968; 1973) to propose the goals achievement matrix (GAM) as an alternative method for the evaluation of plans. Hill's criticism of CBA referred particularly to the [illegible]cy of evaluating public projects on the basis of econo[illegible] efficiency. The major difficulty

identified with PBS relates to the aggregation of costs and benefits accruing to different community sectors (Hill, 1973). Hill asserts that costs and benefits can have meaning only in terms of well-defined objectives. Moreover, items of cost and benefit can only be compared if they can be expressed in relation to a common objective. Because the objectives of individual groups with respect to a particular project will usually be quite different, Hill maintains that it is not legitimate to sum or compare costs and benefits incurred by different groups.

Believing that plans should be evaluated in relation to several objectives, Hill designed the goals acheivement framework for plan evaluation. Implementation of the GAM requires the formulation of a set of goals in advance of the design of alternatives. Goals are defined as "an end to which a planned course of action is directed" (Hill, 1968: 22), and are expressed in terms that permit measurements of the extent to which they are achieved by the proposed plans. In this framework, benefits represent a progression towards a specific goal while costs imply retrogression from the goal. All costs and benefits, then, are expressed in terms of defined goals. The relative importance of each of the goals is estimated and weighted, either via a numerical weighting system or a simple ranking. The level of achievement of each proposal for each goal is then calculated and weighted accordingly and the results are

presented in a matrix (Table 3.2). When possible, the incidence of goal achievements for different community groups are traced and weighted.

Hill (1968) suggests that the costs and benefits can be expressed in one of three ways:

1. Tangible costs and benefits expressed in monetary terms;
2. Tangible costs and benefits expressed quantitatively, but in non-monetary terms;
3. Intangible costs and benefits.

Given that multiple metric information is permitted, the question arises as to how goal achievement levels are to be compared. Hill proffers three alternatives. The first is to simply present decision makers with the goals achievement account, without attempting to synthesize the information.

A second alternative is to sum the weighted indices of goal achievement, the preferred plan being that with the largest index. Since the summary measure is calculated by the addition of items measured on different scales, the index itself is meaningless. Moreover, items for which the unit measures are of a large magnitude will bias the result. Most significantly, in adopting this approach, costs and benefits that refer to different objectives are aggregated, the method then being subject to precisely the

TABLE 3.2

THE GOALS-ACHIEVEMENT MATRIX

Goal description	Goal 1			Goal 2			Goal 3		
Value weight	2			3			5		
	Value	Impacts		Value	Impacts		Value	Impacts	
Incidence	weight	Benefits	Costs	weight	Benefits	Costs	weight	Benefits	Costs
Group a	1	A	D	5	E	-	1		N
Group b	3	H		4	-	R	2		-
Group c	1	L	J	3	-	S	3	M	-
Group d	2	-		2	T	-	4		-
Group e	1	-	K	1		U	5		P
		F	F					F	F

Source: McAllister, 1982.

same criticisms Hill lodges against PBS.

The third approach to comparing goal attainment levels within a goals achievement framework is similar to the second, except that all costs and benefits in the accounting scheme are measured on an ordinal scale. This overcomes the difficulties of aggregating dissimilar value measures to some extent, but considerable detail may be lost. If the weighted indices for individual goals are summed, as Hill advocates, costs and benefits relating to different objectives are again being aggregated.

Lichfield et al. (1975) have focussed criticism on the failure of Hill to define appropriate criteria for the specification of the goals. Given that goals will differ substantially between planning tasks, it is questionable whether general guidelines for the setting of goals could be established. Thus, it was not incumbent upon Hill to attempt to provide such guidance, when goal setting is essentially a political process and will be performed with specific developments in mind.

A further difficulty, and one recognized by Hill (Hill and Werczberger, 1978), is in determining appropriate numerical weights for the individual goals. McAllister (1982: 168) notes: "Valid methods for determining value weights have not been developed yet, and are not likely to be developed. Although value weights are technically a neat solution to the evaluation dilemma, the exercise of having

citizens or decision-makers express their value weights is a very abstract process". In practice, weights need only be determined if a summary index is to be calculated. Given the aforementioned difficulties associated with calculating a summary index and these added problems of determining numerical value weights, the first option, simply presenting the goals achievement account, may be preferable.

The important contribution of Hill lies in his development of an evaluation framework that explicitly accounts for multiple goals. In this respect, the GAM comes closer to providing a suitable approach for resource assessment than either CBA or PBS. The problem that remains, however, is that like the two methods previously discussed, GAM requires that alternative development plans be identified exogenously. Although the evaluation structure closely approximates what is required for resource assessment, the absence of a mechanism to identify alternative resource allocation patterns is still an obstacle in terms of the type of analytical exercise that was to be performed in this research.

3.3.4 Energy Analysis

The purpose of energy analysis is to compare alternative courses of action in terms of their energy

consequences. Gilliland (1978) distinguishes two views of the role of energy analysis; as a comprehensive evaluation method versus its utilization as a tool for measuring a limited set of impacts.

The belief in energy analysis as a comprehensive methodology derives from the energy theory of value - the theory that energy is the ultimate limiting factor. Gilliland (1975) justifies this position since: 1. Energy is the only commodity for which a substitute cannot be found; 2. Potential energy is required to run every type of system; and 3. Energy cannot be recycled without violating the second law of thermodynamics.

Gilliland (1975) has also argued that estimates of economic efficiency will change over time with relative changes in dollar values. Net energy estimates, however, will not be affected by changing dollar values and will remain constant unless there are changes in conversion efficiencies.

McAllister (1982) has sharply criticized claims for energy analysis as a comprehensive evaluation framework. Energy values, he argues, do not provide a suitable measure of social impacts, nor of certain environmental consequences of development. Similar criticisms have been made by Huettner (1976). In particular, he questions the energy theory of value, noting that energy is not the only resource constraint, either in the short or the long term.

Ascribing energy values to certain items requires at least as many untenable assumptions as in attributing pecuniary values, and consequently energy analysis confronts much the same problems as traditional economic valuations in the context of comprehensive evaluation.

In other applications, energy analysis has been restricted to an evaluation of only the energy consequences of development projects. That is, no attempt is made to express social, environmental and economic impacts in energy terms. This is commonly referred to as net energy analysis, and the purpose is to compute energy inputs and compare them with energy gains. Technical problems in the calculation of a net energy index can arise from the fact that energy forms are not always substitutable. McAllister (1982) states: "It is the ability to do specific kinds of work that determines how we value a fuel; the generalized ability to do work is only a crude indicator of this value".

Net energy analysis can play an important role in assessing the energy consequences of development projects, just as CBA may be useful in evaluating economic efficiency. But just as monetary values may misrepresent society's valuation of many items, so may attempts to attribute energy values. The unqualified adoption of an energy value system has little more justification than does a pecuniary value system. Furthermore, in common with other

plan evaluation methods reviewed here, energy analysis must be preceeded by the specification of alternative courses of action. As a framework for resource assessment, therefore, energy analysis is dismissed on similar grounds as CBA and PBS.

3.3.5 Discussion

With the exception of the goals achievement matrix, the plan evaluation techniques reviewed above rely on the specification of information in single metric. Many of the proponents of the various methods have made claims for their comprehensiveness, based on the supposed universality of the respective value measures. From the discussion above, there seems to be little doubt that a single value system cannot adequately represent all of the concerns relevant to development planning and resource management.

Greater opportunity exists with the GAM to incorporate multiple evaluation criteria, by evaluating projects in terms of their ability to satisfy specified goals. Of the methods reviewed above, the GAM comes closest to providing a suitable framework for resource assessment. In common with each of the other methods, however, development alternatives must be specified prior to the implementation of the technique. For the type of analysis proposed here, the question emerges as to how alternative

resource allocation patterns may be identified.

Applying several methods, each for the evaluation of impacts in the subsystem to which it is most suited, represents a further alternative. CBA, for example, might be used to evaluate economic efficiency, while net energy analysis is used to assess energy consequences. The problems of equating impacts and evaluating trade-offs, however, persist. More importantly, there is no opportunity to account for the interactions among the various subsystems, since impacts are assessed independently. This approach also offers no advantages in terms of providing a mechanism by which to identify alternative courses of action, and thus it is no better suited to the type of resource assessment addressed here.

3.4 METHODS FOR IMPACT ASSESSMENT

The development of resources inevitably affects national and regional economies, communities, and the environment. Effective resource management demands that prior to development, decision makers be made aware of the consequences of alternative courses of action. Toward this, several methodological frameworks have been developed that permit analysts to identify and simulate possible changes to the regional economy, local communities and the environment subsequent to an anticipated development. In

some instances, analyses of this type may be a prerequisite to plan evaluation, as discussed in the previous section. Resource management decisions may also be made on the basis of impact assessment information alone. In this section, two impact assessment frameworks are described and discussed, input-output analysis and integrated socio-economic simulation models. The discussion of input-output models focusses on extensions to the traditional economic accounting framework that incorporate ecologic-economic interactions.

3.4.1 Input-Output Models

Input-output analysis was developed by Leontief during the 1930's for the purpose of describing the pattern of sales and purchases of goods and services among the various sectors of the U.S. economy. Most developed nations now possess a national-level input-output accounting framework. Input-output analysis has also achieved popularity in recent times as a tool for regional analysis.

In the input-output flows table (Table 3.3), each row indicates how the output of the respective sector is distributed to all other sectors. The columns represent the purchases made by each sector from all other sectors. The accounting identities can be represented algebraically: X_{ij} represents the flow of output from sector i to sector j, Y_{ik}

TABLE 3.3

THE STRUCTURE OF A SIMPLIFIED INPUT-OUTPUT TABLE

Outputs ⟶ / Inputs ↓	Industry				Final Demand	Total Gross Output
Industry 1						
Industry 2						
Industry 3						
Industry 4						
Value Added						
Total						

is the flow of output from sector i to the final demand sector k, and X_i is the total output from sector i. Hence:

$$\sum_{j=1}^{n} x_{ij} + \sum_{k=1}^{m} Y_{ik} = X_i \text{ , for each i.} \qquad 3.1$$

The input-output flows table provides the basis for the calculation of the input coefficients matrix. a_{ij} is a technological input coefficient and represents the value of each input i required per unit of output of j. That is;

$$a_{ij} = x_{ij} / X_j . \qquad 3.2$$

Rewritting 3.1:

$$\sum_{j=1}^{n} a_{ij} X_j + \sum_{k=1}^{m} Y_{ik} = X_i . \qquad 3.3$$

These accounting identities may be expressed in matrix form:

$$AX + Y = X, \qquad 3.4$$

where A is the matrix of input coefficients, the a_{ij}'s, X is a vector of total outputs and Y is a final demand vector.

Factoring equation 3.4:

$$X - AX = Y,$$

$$[I - A]^{-1}X = Y, \text{ and}$$

$$X = [I - A]^{-1}Y, \qquad 3.5$$

where I is the identity matrix.

The inverse matrix, known as the Leontief inverse, has powerful analytical capabilities. Each element represents both the direct and indirect impacts on all other sectors in the economy of a unit change in the value of final demand or output of the respective sector (Isard, 1975). This is particularly useful in the forecasting context, since it is possible to simulate changes in the total economy that may result from anticipated changes in final demand or total outputs. It is worth noting here, that for the plan evaluation frameworks reviewed previously, the information that can be generated via an input-output model potentially has considerable value, since it provides a useful means of assessing the economic impacts of proposed development plans. Alternative forecasting approaches for input-output models are reviewed at length in Hewings (1977).

Significant developments in the field of input-output analysis have been in the specification of interregional frameworks. Prominent examples of interregional models are those of Isard (1951), Moses (1955) and Leontief and Strout (1963). The significant

problems of obtaining accurate interregional flow data are described by Jensen and MacDonald (1982).

Input-output analysis as described above relates exclusively to the investigation of economic flows and the economic consequences of changes in demand or output. Of greater interest here are the environmental extensions to classical input-output models.

3.4.1.1 Environmental Extensions

Recognizing that input-output models had proved useful in representing the interdependencies of the economy, several analysts postulated that input-output frameworks might also have utility in analyzing interactions in a broader sense. The traditional input-output framework has been modified in several different ways to permit analysis of environmental-economic interactions.

The most elementary approach has involved the use of input-output tables to obtain estimates of pollution associated with economic production or changes in final demand (Hite and Laurent, 1972; Shefer, 1973). This is achieved through the definition of a matrix of pollution coefficients $p = [\ p_{kj}\ ]$, where each element p_{kj} represents the amount of pollutant k (eg., sulphur dioxide) generated per dollar of output of sector j. These coefficients are analogous to the technical coefficients (a_{ij}'s) and, when

multiplied by the Leontief inverse, yield estimates of the pollution generated throughout the economy and corresponding to a specified level of final demand.

Mathematically:

$$P^* = [\, P\ (I - A)^{-1} \,]\ Y, \qquad 3.6$$

where P^* is a column vector with k rows, representing the total amount of pollution generated per dollar of final demand. This augmented input-output model can be used to estimate the environmental impacts associated with changes in final demand or the introduction of new industries (Folk and Hannon, 1974; Hite and Laurent, 1972; Shefer, 1973).

Changes in the level of activity in one economic sector typically initiates changes in other sectors. As noted previously, the Leontief inverse captures these indirect effects, such that the input-output model is capable of simulating economy-wide impacts of specified adjustments. The important characteristic of the approach described above is that by adding a matrix of pollution coefficients, it becomes possible to also estimate changes in pollution levels beyond those that result from a different level of activity in one particular sector.

In a similar way, input-output multipliers can be used to simulate the effects upon levels of energy consumption of specified changes in final demand. An

analysis by Herendeen (1974), for example, sought to estimate the energy intensity of household expenditures as a function of income. In another study, Bullard and Herendeen (1975) estimated the total energy cost of goods and services in the United States. Blair (1979) applied an energy input-output framework to investigate the regional impacts of the construction of power generating facilities, while Just (1974) has assessed the consequences of introducing new energy technologies, including coal gasification. An extensive review of energy input-output frameworks can be found in Miller and Blair (1984).

In an alternative approach to integrating economic and environmental systems within an input-output framework, Cumberland (1966) added rows and columns to the standard industry-by-industry table, which identify the environmental benefits and costs of development. The entries of one row are estimates of the environmental benefits of a project accruing to each economic sector, while a second row represents the environmental costs of a proposed project. The entries of both rows are dollar valuations of the associated environmental costs and benefits. An environmental balance row represents the net environmental benefits, by sector, while an environmental balance column measures the post-development costs, by sector, of restoring the environment to acceptable standards.

In essence, Cumberland's model is a cost-benefit analysis structured within an input-output framework. A major limitation is that the model demands that environmental costs and benefits be ascribed dollar values, and the difficulties associated with this have been discussed at length in the critique of cost-benefit analysis.

Also maintaining the standard industry-by-industry structure, Daly (1968) designed an alternative economic-ecologic input-output model. In his model, the accounting framework is partitioned into four quadrants (Table 3.4). The upper-left quadrant of the table is the domain of traditional economics; that is, the analysis of inputs and outputs to and from the various economic sectors. The entries of the lower-right quadrant are the flows between the ecologic sectors. Connecting the two systems, the quadrants of the off-diagonal contain the flows of inputs from economic sectors to the ecologic sectors (the upper-right quadrant) and the flows from the ecologic sectors to the economic sectors (the lower-left quadrant).

Not satisfied with simply a descriptive device, Daly sought to convert the table to an analytical tool useful for planning and prediction, through the calculation of a matrix of technical coefficients. The difficulty is that the entries of Quadrant 2 are in dollars, while those of

TABLE 3.4

THE DALY INPUT-OUTPUT MODEL*

	INPUT TO										TOTAL
	Agriculture (1)	Industry (2)	Households (Final Consumption) (3)	Animal (4)	Plant (5)	Bacteria (6)	Atmosphere (7)	Hydrosphere (8)	Lithosphere (9)	Sink (Final Consumption) (10)	
	Quadrant (2)			Quadrant (1)							
1. Agriculture	...	q_{12}	...	...	...	...	q_{17}	...	...	...	Q_1
2. Industry	q_{21}	(q_{22})	q_{23}	...	...	...	q_{27}	...	...	...	Q_2
3. Households (primary services)	...	q_{32}	...	...	...	...	q_{37}	...	...	...	Q_3
	Quadrant (3)			Quadrant (4)							
4. Animal	...	...	...	...	...	...	q_{47}	...	...	...	
5. Plant	...	...	...	...	...	...	q_{57}	...	...	...	
6. Bacteria	...	...	...	...	...	...	q_{67}	...	...	...	
7. Atmosphere	q_{71}	q_{72}	q_{73}	q_{74}	q_{75}	q_{76}	(q_{77})	q_{78}	q_{79}	$q_{7.10}$	Q_7
8. Hydrosphere	...	...	...	...	...	...	q_{87}	...	...	...	
9. Lithosphere	...	...	...	...	...	...	q_{97}	...	...	...	
10. Sun (primary Services)	...	...	...	...	...	...	$q_{10.7}$	...	...	...	

* where q_{ij} represents intersector and intrasector material flows, and Q_i represents total sector output.

Source: Daly, 1968.

Quadrant 1 are physical measures of the environment, kilograms of alfalfa, for example. The totals, represented as the Q's in Table 3.4, are therefore undefinable, as are the technical coefficients.

A limitation common to the models of Cumberland and Daly derives from the use of the industry-by-industry framework. In the economic system, the multiple outputs of an industrial sector are represented as a dollar aggregate of all its outputs. Although this may result in a simplified representation of inter-industry linkages, particularly in the case of multi-product industries, it is usually accepted as necessary in input-output analysis. In extending the framework to account for ecologic factors, however, two difficulties are encountered. First, sectors defined for the purposes of economic analysis may not represent appropriate groupings of industries when ecologic effects are being considered. Secondly, ecologic effects must typically be expressed in multiple metrics.

To overcome these limitations, ecologic-economic input-output models have been specified in which there may be more commodities than industries and multiple products from environmental processes. This extension is not unique to ecologic-economic input-output models, as the Canadian accounts table is a commodity-by-industry table of strictly dollar flows. The two best known ecologic-economic models of this type are those of Isard (1969; 1972) and Victor

(1972).

The framework designed by Isard is illustrated in Table 3.5. The structure is similar to that of Daly, in that the accounting framework is partitioned into four quadrants, two of which account for the flows between the economic and ecologic sectors (the upper-right and lower-left quadrants, respectively), whereas the other two represent flows within each of the economic and ecologic sectors (the upper-left and lower-right quadrants, respectively).

One of the major difficulties associated with the Isard framework is that the data necessary to complete the interprocess coefficient matrix of the ecologic system is generally not available. Recognizing these data constraints, Victor (1972) excluded the ecologic interprocess matrix from his model. The Victor model is based around the Canadian input-output accounting framework for the economy, and includes a number of additional matrices and vectors to account for environmental-economic interactions. As in the Isard model, entries for the ecologic sector are measured in appropriate physical units, while those of the economic sector are expressed in monetary terms.

Both Isard and Victor have utilized their ecologic-economic input-output models to address planning problems from an environmental perspective. Isard (1975),

TABLE 3.5

THE ISARD INPUT-OUTPUT MODEL

		Agriculture	Textile		Petroleum refining		Sport fishing		Plankton production	Herring production	Cod production
Economic Commodities	Wheat										
	Cloth										
				Economic System: Inter-sector co-efficients 2				Ecologic Processes: Their input and output co-efficients re: economic commodities 1			
Ecologic Commodities	Crude oil				-						
	Water intake				-						
	Alkalinity				+						
				3 Economic Sectors:.. Their input and output co-efficients re: ecologic commodities				4 Ecologic System: Interprocess Coefficients			
	Detritus										
	Plankton								+	-	
	herring									+	-
	cod										+

Source: Isard, 1969.

for example, demonstrates how data within the flows table can be manipulated for the purposes of simulating the amount of pollution generated within a region, given specified levels of economic output. The capabilities of the framework to contribute to regional planning are also demonstrated through an assessment of the environmental repercusions of a boat marina development in Plymouth Bay, Massachusetts (Isard, 1972).

Victor (1972) evaluates the effects on the environment of expenditures on final demand, in terms of both demands upon natural environmental assets and outputs to the environment (eg., pollution). A case study involved an assessment of the effects on the environment of a move towards increased use of public transportation.

The analyses of Isard and Victor involved extracting information from the accounting framework and performing the necessary manipulations, rather than manipulating the table as a whole, as is characteristic of economic simulation exercises. The accounting table, therefore, is simply a device for organizing information on economic-environmental interactions. In this respect, though, the frameworks are interesting conceptualizations of the relationships between economy and environment, and have considerable heuristic value. Since the development of these various frameworks for environmental-economic analysis, interest in their development has been

maintained, and various extensions and refinements to the models discussed above have been proposed (see, for example, Johnson and Bennett, 1981; Muller, 1979; Steenge, 1977).

Input-output models, however, are not well suited to resource assessment. Like the plan evaluation techniques reviewed in the previous section, development alternatives must be pre-specified. Moreover, input-output analysis provides a poor basis for the evaluation of the relative merits of one alternative versus another. The purpose of input-output analysis is to model the functioning of a system and thereby provide a basis for the estimation of impacts that may result from changes to that system. The potential value of this information as an input to plan evaluation frameworks has previously been acknowledged. Also, attempts to develop ecologic-environmental input-output models address concerns for better integrated approaches to analysis. The tasks for which input-output frameworks are best suited, however, are not consistent with the analytical objectives of this research.

3.4.2 Integrated Socio-economic Simulation Models

The models discussed in this section are used for similar purposes to input-output models in that they are models of a system designed to provide a basis for

estimating changes that may occur as a result of development projects. Integrated socio-economic simulation models, though, attempt to account for a broader range of impacts than input-output analysis. Perhaps the best known models of this type are those prepared for the Club of Rome in the early 1970's (Forrester, 1971; Meadows et al., 1972). Using global averages, these models attempt to link future population growth, natural resources, agricultural production, industrial production and pollution, the five factors that are considered to determine and ultimately limit future growth.

Integrated socio-economic impact assessment models have also been applied extensively at the local or regional scale to estimate the impacts of undertaking specified development projects (Fookes, 1977; Power et al., 1980), and these models have potentially greater relevance for this research. Leistritz and Chase (1982) identify the basic functions of these models to be the analysis and evaluation of socio-economic impacts and the development of strategies and measures to ensure that benefits associated with large-scale projects are realized while adverse impacts are minimized. The value of these models lies in their ability to systematically delineate interrelationships among economic, demographic and social factors (Murdock et al., 1979).

Murdock and Leistritz (1980) proffer several

criteria by which to evaluate models of this type. One major criterion concerns the extent to which the various submodels are integrated, rather than simply applying separate methodologies to the same problem. Development of a well-integrated and comprehensive model is largely dependent on the ability to design the interfacing components. The ability to incorporate structural changes in the model over time and to account for feedbacks amongst the system submodels are additional criteria by which models are evaluated.

Leistritz and Murdock have undertaken several extensive reviews of regional socio-economic impact assessment models (Leistritz and Chase, 1982; Leistritz and Murdock, 1981; Murdock et al., 1979). The models reviewed have components relating to economics, demographics, population and employment distribution, public services, and social aspects, but most models do not include all components. The methodological characteristics of individual components vary amongst the models reviewed. The economic component, for example, is based on input-output analysis or economic base models. Demographic characteristics are represented by cohort-component-survival models or simple employment-population ratios. Economic and demographic components are interfaced via employment-migration or employment-population ratios. The distribution of

employment and population to regional subareas is handled by gravity models, percentage shares, or linear programming models. In all of the models reviewed, public service projections are estimated on the basis of service-population ratios.

In light of their reviews, Murdock et al. (1979) have made several major criticisms of these models. Most importantly, they suggest that many of the models developed to date do not effectively achieve integration of the various model components. Because the success of the these models ultimately lies in their ability to accurately interface the components, improved design of the interfaces is an important task for further research.

Apart from the problems that are inherent to existing models, for the purposes of this research, integrated socio-economic simulation models provide few advantages over input-output analysis. The capability to account for a broader range of impacts exists, but these models also demand that development alternatives be specified exogenously. Additionally, the integrated models do not provide any clear basis for the evaluation of the relative merits of different development options, nor the capability to assess the potential to achieve development goals. The primary function of these models, like input-output analysis, is to provide a basis for estimating changes to a socio-economic system as a result of

anticipated or proposed developments. With this capability, these models may be of considerable value when the objective is to evaluate a discrete number of pre-defined alternatives. These methods are not suited to resource assessment, however, which, as it is defined here, is largely devoted to the purpose of identifying alternative options in resource use.

3.5 SUMMARY

Methodological frameworks appropriate for two different, but closely related, planning tasks have been reviewed. One important distinguishing characteristic is that impact assessment models provide no explicit criteria for selecting amongst various alternatives. Expected alterations in baseline conditions as a consequence of a proposed development can be used as input to the models and the system-wide changes estimated. This procedure can be performed repeatedly to investigate the consequences of alternative proposals, as well. Model output, though, provides no explicit criteria by which to choose between the alternatives. These decisions must be undertaken by entrepreneurs and analysts in light of the information provided. In contrast, analysis performed under plan evaluation model frameworks works explicitly towards the calculation of indices that provide a basis for selecting a

preferred course of action.

The extent to which the various models reviewed have been successfully developed for comprehensive and integrated analysis differs markedly. In general, the plan evaluation methods rely on information specified in single metric and the issue of comprehensiveness revolves around questions of value measures. Only the goals achievement matrix provides explicitly for the measurement of impacts in terms of multiple evaluation criteria or goals. The impact assessment methodologies reviewed have been extended to include multiple metric information, and more adequately address concerns for comprehensive analysis.

For all of the frameworks reviewed in this chapter, a prerequisite to evaluation of proposed resource developments is a defined set of alternative plans. Concerns may relate, however, to the suitability of any of the alternatives proposed. Houghton (1974) has questioned the value of plan evaluation methods when none of the suggested courses of action are particularly suitable, but when the possibility of further, more appropriate plans exists. The issues are clearly those of how the alternatives are originally designed and whether the analytical frameworks provide a facility to readily identify appropriate modifications to proposed plans.

The questions of interest here, though, do not involve a limited set of pre-specified resource-use

strategies. No explicitly defined alternatives exist, for example, with respect to the allocation of resources to energy production from plantation forests in Eastern Ontario. In fact, a major objective of the research is to develop an analytical framework by which to identify possible resource allocations, given goals relating to economic efficiency, regional development, energy and environment. In the following chapter, the models reviewed are considered to be considerably better suited to this specific task.

CHAPTER 4

METHODOLOGIES FOR RESOURCE ASSESSMENT 2: LINEAR OPTIMIZATION MODELS

4.1 INTRODUCTION

Linear programming models have been extensively applied in resource management and other planning fields since their development in the late 1940's. The first part of this chapter outlines the general structure of single-objective linear programming models and briefly reviews selected applications to resource management problems. Attention is given to some recent developments in single-objective programming that reflect a significant shift in perceptions of the role of programming techniques in resource management, and public sector planning in general. Multiobjective programming models are then introduced and the various solution procedures for multiobjective programming problems are listed. Goal programming models are described in greater detail and selected applications in the field of resource management are briefly reviewed.

4.2 SINGLE-OBJECTIVE LINEAR PROGRAMMING

Programming models can be used to allocate limited resources in order to achieve specified objectives in the most "efficient" manner. The models search for the "optimal" alternative, according to defined criteria. Available programming techniques include linear programming, non-linear programming, integer programming, and dynamic programming. The format selected will depend upon the specific nature of the problem, the data available, and the assumptions employed. Linear models have found the widest application in resource management due to their inherent simplicity and generality, and the widespread availability of computer-based solution procedures. Only linear programming models, in both single- and multiple-objective systems, will be reviewed here. Extensive descriptions of programming theory and other programming techniques may be found in standard texts such as Ignizio (1982) and Wu and Coppins (1981).

4.2.1 Definitions, Structure and Interpretation

Single-objective programming models achieve the maximization or minimization of a specified objective,

subject to a set of resource constraints. Common examples of objective functions include profit maximization, production cost minimization, minimization of travel distances, and minimization of energy use. The constraints of the model, represented as linear equalities or inequalities, may reflect physical resource limitations, desired levels of economic activity, institutional regulations, levels of public servicing, and equity concerns, among many others (Roseth, 1970).

The single-objective optimization problem (in its maximization form) is defined mathematically as:

$$\text{maximize } Z = c'x, \qquad 4.1$$

subject to:

$$Ax \leq b, \text{ and} \qquad 4.2$$

$$x \geq 0, \qquad 4.3$$

where x is a column vector of n decision variables x_j, c' is a row vector of n specified constants in which any element c_j represents the change in the objective function corresponding to a unit change in decision variable x_j, A is an m-by-n matrix of technical coefficients in which any element a_{ij} accounts for the utilization of resources per unit of decision variable x_j, and b is a column vector of m resource constraints or targets.

A feasible region, denoted as X, is defined by the

problem constraints (equations 4.2 and 4.3) and the optimization program seeks to find an element x* of X that yields a maximum value for the function Z. Given the existence of a feasible region, there will be at least one optimal solution to the problem, and in most cases this will be at the intersection of the regions defined by two or more constraint functions (Wu and Coppins, 1981). Multiple optima will exist if the objective function lies parallel to a constraint that bounds the feasible region. All points on the edge or surface of the feasible region defined by that binding constraint are then optimal, which means that alternative combinations of the decision variables will yield a solution that maximizes or minimizes the objective function.

In the optimal solution, constraint functions for which the right-hand-side value is exactly met are referred to as binding constraints, whereas those for which there is a deviation from the specified value are referred to as non-binding constraints. The deviation from the right-hand-side of a non-binding constraint is a measure of slack in the system, a surplus of a particular resource, for example.

Sensitivity analysis is used to determine the impact on the decision variables of changes in the coefficients and structure of the linear programming model. In any application of a linear programming model, sensitivity

analysis is extremely important and may be conducted in response to a variety of "what if" possibilities. Technological developments, for example, may affect the efficiency of resource use, and new reserves might be discovered. Changing economic conditions may affect production costs and profitability, while expectations with respect to productivity may be adjusted in the future. Also, model formulation may require that certain coefficients and constants in the model be estimated when data are unavailable. Sensitivity analysis also provides the opportunity to assess the implications of uncertainty associated with the estimated values.

For sensitivity analysis, linear programming models can be altered in the following ways (Ignizio, 1982):

1. Changes in the objective function coefficients (c_j's);
2. Changes to the constraint right-hand-sides (b_i's);
3. Changes in the technical coefficients (a_{ij}'s);
4. Addition or removal of a constraint; or
5. Addition or removal of a variable.

For 1 through 3, the changes may be discrete or involve adjustments over a range of values for a specific parameter. Adjustments performed over a range of values are referred to as parametric analysis.

Calculation of the optimal solution to a linear programming problem, the so-called primal solution, will also permit the calculation of a set of dual activity values, which provide further useful information for sensitivity analysis. One set of dual values indicates the sensitivity of the objective function to unit changes in the right-hand-sides of the corresponding constraints. For a maximization problem, the dual values will be positive and reflect the increase in the objective function for unit increases in the availability of resources. Conversely, dual variable values in a minimization problem are negative, indicating decreases in the objective function for corresponding unit changes in the binding constraints. Dual values do not exist for non-binding constraints, since the optimal values of the decision variables are not explicitly determined by these particular limiting conditions. A further set of dual values indicates the sensitivity of the optimal solution to the coefficients of the decision variables in the objective function.

4.2.2 Single-Objective Linear Programming and Resource Management

Linear programming models have been applied to a wide variety of planning problems in both the public and private sectors. Although the general structure of the

models is similar, and as described above, the specific characteristics of the individual models vary considerably, even amongst models applied to similar management problems. In resource management, linear programming models have been developed to assist decision making with respect to the following:

1. Farm operations (Dean et al., 1969; Henderson, 1968; Lindner, 1969);
2. Regional and national agricultural resources (Craddock, 1970; Duloy and Norton, 1973; Heady and Hall, 1968);
3. Game and fish management (Rothschild and Balsinger, 1971);
4. Water resource management, including reservoir storage and yield, water quality management, irrigation, and river basin management (Loucks et al., 1981; Marks and Cohon, 1975); and
5. Recreation planning (Cheung and Auger, 1976; Meier, 1968).

4.2.3 Single-Objective Linear Programming and Resource Assessment

An appealing feature of programming models is that they can be applied to a variety of research questions. A programming model may be designed, for example, to

represent the functioning of a system. The constraints and objective function, in this context, are expressed according to a perception of how the system under consideration operates. The model can then be used to predict what is likely to happen under specified conditions, in much the same way as the simulation models previously discussed are used (see, for example, Heady, 1973). Since the purpose is to simulate the effects of a discrete set of specified alternatives, applications of this type have little relevance for this research, where a major objective is to identify alternative options for resource use.

Programming models have also been used to identify a solution that is "best" in terms of the criteria specified in the model (by the constraints and objective function), and the solution represents a target to which it is expected that policy should be directed (see, for example, Coelho and Williams, 1978; Heady and Spaulding, 1979). In the sense that the model is used to identify a particular resource allocation strategy, applications of this type come closer to the type of analysis under consideration here. For several reasons, however, the use of programming models to identify a single "optimal" solution has been sharply criticized.

Much of the criticism has focused on the inability to adequately represent the planning problem within the

rigid mathematical framework of a programming model. If the planning problem cannot be adequately represented, the question then arises as to how appropriate the solution generated is in terms of resolving the problem at hand.

A specific concern relates to the necessary exclusion of certain planning criteria from the mathematical model. Notable examples of factors that may be of importance in evaluating resource management options, but which are not amenable to specification within the linear mathematical framework, are environmental aesthetics, amenity values and certain social criteria, such as community feeling.

Concerns also relate to the fact that the model may poorly represent relationships between variables. In many instances, the exact nature of the relationships between the variables are unknown and the coefficients may at best be rough estimates. Arnold and Bennett (1975), for example, discuss the difficulties of accounting for uncertainties in weather conditions, markets, interest rates, subsidies, and biological events such as pests and diseases, all of which confound the specification of optimization models in agriculture. Even when model coefficients can be specified accurately, the fast rate of technological and social change may outdate models very quickly (Ackoff, 1977; Arnold and Bennett, 1975; Cheung and Auger, 1976).

A related concern is the requirement that all

relationships be linear. This provides for ease of understanding and computational efficiency. Many relationships in the social and natural world, however, are not linear. The development of non-linear models has provided the opportunity to specify relationships more accurately within a programming framework. Difficulties associated with such models, though, are that they require a much higher level of mathematical competence and solution algorithms are not as readily available as for linear programming. Perhaps for these reasons, non-linear models have found far less practical application.

To some extent, the implications of these problems in model specification can be assessed with respect to a particular problem by examining the sensitivity of the model solution to changes in the various coefficients, as described earlier. These difficulties, though, are the rule rather than the exception, and doubts as to the value of generating a single "optimal" solution via a programming framework are well-founded.

Multiple optima and the existence of sub-optimal solutions are cause for further concern when programming models are used in this normative sense. Multiple optima, it was noted previously, may exist when the objective function lies parallel to a constraint function. In this case, alternative combinations of the decision variables will achieve the optimal value for the objective function.

Additionally, unless there is only one feasible solution to a programming problem, several solutions will exist that are almost as good as the solution generated to the mathematical problem. While a similar level for the objective function is achieved with these sub-optimal solutions, the associated resource allocations may be quite different from that associated with the mathematical optimum. Like multiple optima, therefore, sub-optimal solutions represent alternative resource development strategies that are at least good with respect to the specified decision criteria.

The existence of multiple optima and sub-optimal solutions may be of interest, since they imply that flexibility exists in terms of the manner in which resources are used to achieve specified objectives. Some opportunity might also exist to assess these alternative solutions according to their performance in relation to decision criteria represented in the model constraints. Although all of the solutions generated imply similar results in terms of the objective function, some solutions might be preferable in that they involve, for example, lower capital expenditures, higher levels of employment, less pollution and so forth. All solutions, of course, satisfy the constraints, but on further inspection, some of the alternatives might be considered preferable in terms of certain modelled criteria. In addition, if there are

decision criteria that cannot be included in the model, it may prove possible to compare the various alternative solutions in relation to these criteria in some qualitative sense.

Since sub-optimal solutions to a programming model will almost always exist and multiple optima may sometimes arise, the search for, and promotion of, a single "optimal" solution is at least naive. More recently, alternative applications of programming models have involved the use of models to identify a range of alternatives, to discern their possible impacts, and to illuminate potential conflicts. In this context, optimization is not an automated form of decision making, but represents a useful aid to decision makers (Arnold and Bennett, 1975).

The purpose in developing the programming model is not to provide some definitive answer to a planning problem. In constructing the model, the analyst reveals what are perceived to be the most important components involved and the nature of the interactions amongst them. By varying assumptions with respect to the stated conditions, insight is gained as to the influence different factors may have on the achievement of objectives and patterns of resource allocation. Through this method, the model is used to provide essential information as to the importance of different factors involved, such as production relationships, resource constraints, policy and

established objectives. The role of the analyst is no longer construed to be the provision of a resource allocation plan, but to inform. Liebman (1976) states: "Using quantitative tools in this fashion is philosophically different; it requires explicit recognition that the analysts objective is the provision of intuition, insight and understanding which supplements that of the decision-makers".

Compared to traditional normative applications of programming models, where the primary purpose was to identify a "best" solution, the discussion immediately above refers to a different type of analysis in which there is an attempt to identify and assess a range of alternatives via the programming model. This clearly is more consistent with the type of problem proposed here. Important progress has been made in the development and use of programming models for use in the latter context and these are briefly reviewed in the following section.

4.2.4 Recent Developments in Optimization for Resource Management

Traditional applications of linear programming models have sought to identify an optimal solution to a management problem via the mathematical model, the solution representing a target to which it is expected that policy

should be devoted. For reasons stated above, the optimal solution to the mathematical problem may often not be the most appropriate response to the planning problem. Recognizing this, several authors have defined a different role for optimization methods, in which the analyst uses the mathematical model to identify a set of alternative resource allocation patterns and explore the implications of these.

One approach to this has involved searching the feasible region of the programming problem, as defined by the constraints, in order to identify a range of alternative, near-optimal, feasible resource allocation patterns (Brooks, 1958; Church and Huber, 1979). Chang et al. (1982a) note that while adjusting various model parameters has been used extensively to define alternative solutions, the use of optimization methods to generate alternatives is relatively new.

The team of Chang, Brill and Hopkins have recently developed three further approaches to generating alternatives using optimization methods. Cognizant of the technical and philosophical difficulties inherent in identifying "optimal" solutions to planning problems via programming techniques, attempts were made to develop procedures by which to generate a set of solutions that were not only good with respect to the mathematical optimum, but were also substantially different from each

other in terms of the values of the decision variables. The rationale for this was that decision makers could then be presented with a range of alternative resource development options. The three methods developed are the branch and bound screening (BBS) method (Chang et al., 1982a), the Hop, Skip and Jump (HSJ) method (Brill et al., 1982) and a random generating method (Chang et al., 1982b).

In an evaluation of the three methods, Chang et al. (1982a) found that not only did each method generate alternatives that were different from each other, but also that the sets of alternatives differed. In view of this, and since all of the methods were judged to be computationally efficient, the authors suggest that it may be fruitful to employ more than one method, in that way developing alternatives that are not only different, "but different in different ways".

The application of these generating methods implicitly assumes that a planning problem exists and that the role of the analyst is to provide a set of alternatives representing possible appropriate responses to the management problem. Procedures based on linear programming models have also been recently developed which are directed at assessing the need for policy and identifying directions which policy may take (Chapman et al., 1984). The analysis is based on the notions of flexibility and criticality in resource use. Flexibility is defined as a measure of the

difference or range among alternative feasible solutions to a programming problem. Applied to resource management problems, flexibility measures provide an assessment of the adequacy of the resource base relative to specified demands. Criticality refers to the importance of a particular resource unit for a specific use. In the agricultural land use context, a unit of land is regarded to be critical for a use if the attainment of one or more goals is threatened or precluded in the event that the allocation is reduced below a known non-zero value (Chapman et al., 1984). In other words, a land unit is critical in terms of a particular use if a large proportion of the land must be allocated to the activity. Measures of criticality are useful in identifying those components of the resource base that may demand policy intervention.

In an analytical context, Chapman et al. (1984) base assessments of flexibility and criticality on the dimensions and configuration of the feasible region. Specifically, measures of flexibility are obtained through estimates of the area or volume of the feasible region. This derives from the observation that the distance between the boundaries is a reflection of the range in options that exist (Wu and Coppins, 1981). Estimates of criticality are based on the minimum values a variable may take while remaining within the bounds of the feasible region.

These measures of criticality and flexibility have

considerable value in defining the need for policy intervention. When there exists little flexibility in the system, it is an indication that goals with respect to the use of resources may not be met, therein suggesting a need for careful monitoring or appropriate policy (Chapman et al., 1984). Measures of criticality are useful in identifying the extent to which particular resource-use allocations may inhibit goal achievement. In this respect, they provide an indication of those resource units for which management initiatives are most important.

An important distinction of this type of analysis is that there is no concern with the identification of optimal or near-optimal solutions. The measures of flexibility and criticality are based entirely on the configuration and size of the feasible region and are never related to optimal solutions in terms of the decision variables.

Recently, studies have also demonstrated that the capabilities of optimization methods may be enhanced by linking them to other models. In particular, the linkage of simulation and optimization models has provided a useful structure for natural resource management problems (Jacoby and Loucks, 1972; Kelly and Spofford, 1977; Lonergan, 1981, 1983; Swartzmann and Van Dyne, 1972). Simulation models provide the opportunity to examine the impacts of specified developments in considerable detail, but these models provide no explicit guidance in the design of management

alternatives. Conversely, optimization models provide useful input in formulating development alternatives, but in the interests of simplicity and tractability, the representation of reality is usually highly simplified. In linking the two, an optimization model is used to identify management alternatives, the implications of which can be examined in detail via the simulation model (Brill, 1979). As Lonergan (1983) notes, the models are not run simultaneously, but in a sequential and iterative process. A set of initial conditions are input to the simulation model and the model is run for a specified planning period. The simulation model is "interrupted", and relevant information is supplied to the optimization model. A development plan is generated and a new set of initial conditions are provided for the simulation model.

Simulation models provide a valuable dynamic component to management models when linked with the static optimization framework. Moreover, Lonergan (1981) suggests that the iterative running of the linked model structure and standard manipulations of the optimization model impart considerable flexibility and adaptability to the methodology. Of significance also is the explicit recognition that particular systems must be represented by appropriate methods, as the ecosystem by simulation models and decision making in the economic sector by programming techniques. In this respect, simulation/optimization models

make a valuable conceptual and analytical contribution to integrating economy and environment.

4.2.5 The Suitability of Single-Objective Programming for Resource Assessment

A distinctive feature of programming models is that they can be developed in order to address alternative types of research questions. In some applications, programming models are used essentially as simulation models, in an attempt to predict "what will be" under specified conditions. Applications of this type have little relevance for this research, for the same reasons input-output and other simulation models were previously rejected for resource assessment analysis.

Programming models have also been used in a normative sense, where the primary purpose is to identify some "optimal" resource allocation pattern. Applications of this type have been the target of extensive criticism, especially in the resource planning context. Much of the dissatisfaction derives from the observation that programming models can at best be an approximation to the decision problem and, given this, the solution to the mathematical model may not be an appropriate response to the actual planning problem.

Further observations relate to the fact that there

may be multiple optima and that there will usually exist many solutions that are almost as good as the optimal solution. These alternatives may imply very different resource allocations which achieve or almost achieve the same level in terms of the decision criteria. Alternative options in resource use may be of considerable interest when it comes to formulating plans for development.

More recently, programming models have been applied to the specific task of identifying a range of alternative solutions and in evaluating the impacts of these alternatives. Applications of this type are more consistent with the analytical objectives of this research.

A major limitation remains, however, in terms of the suitability of single-objective models for resource assessment. The difficulty is that the single-objective model does not offer an adequate framework for considering the potential conflicts when multiple goals exist. Planning concerns beyond those represented in the objective function can be incorporated in the single objective model via the constraints. This, however, is a rather inflexible way of including development goals. A model that is feasible indicates that there is no major contradiction in the concerns expressed by the constraints. If the model is infeasible, this indicates that there is a conflict between at least two of the constraints. Beyond this, the model directly provides little information on the specific

relationships between development goals. Hence, single objective models provide a poor basis for addressing the fourth question in resource assessment, which relates to nature and extent of goal conflicts. The following sections describe multiobjective programming techniques, the major impetus for the development of which derives from the observation that many management decisions are subject to several, often incommensurate, goals.

4.3 MULTIOBJECTIVE OPTIMIZATION

The need to evaluate development projects with respect to multiple, and often conflicting, goals is widely accepted in both private and public sector planning. Important questions are concerned with the extent to which specified development goals can be satisfied under different resource allocations. Related questions concern the nature and extent of conflicts between the specified goals. Single-objective programming models provide a framework by which to identify alternative options in resource use. Moreover, they have some capability to address, at least in part, the first three questions relevant to resource assessment (see Section 1.1). The single-objective framework, however, provides a poor basis for addressing the fourth question, which relates to the nature and extent of goal conflicts. In concept,

multiobjective programming models appear to be better suited to addressing this important fourth question, while also providing an adequate framework within which to address the other three questions relevant to resource assessment.

Multiobjective programming, known also as vector optimization, was developed during the early 1950's by Koopmans and, separately, by the team of Kuhn and Tucker (Cohon and Marks, 1975). Extensive research in the field of vector optimization techniques did not occur until the 1960's, however, when there was increasing concern for the need to accommodate multiple objectives in public planning decisions. Vector optimization theory has subsequently developed very rapidly, and there are now more than 20 different solution techniques available (Cohon and Marks, 1975). The following section introduces terminology pertinent to this field of analysis.

4.3.1 Terminology and Definitions

The vector optimization problem (in its maximization form) can be represented mathematically as:

$$\text{Max } Z(x) = [Z_1(x),\ Z_2(x), \ldots,\ Z_p(x)], \qquad 4.4$$

subject to:

$$g_i(x) \leqslant 0 \quad ; \; i = 1, 2, \ldots, m, \qquad 4.5$$

$$x_j \geqslant 0 \quad ; \; j = 1, 2, \ldots, n, \qquad 4.6$$

where $Z(x)$ is an objective function comprised of p objectives, x is an n-dimensional vector of decision variables, and $g_i(x)$ is a set of m constraints.

As in the single-objective programming problem, the resource constraints in combination with the non-negativity constraints define a feasible region, X, in n-dimensional Euclidean decision space. Formally:

$$X = [x: x \in R, \; g_i(x) \leqslant 0, \; \forall \; i, \; x_j \geqslant 0, \; \forall \; j], \qquad 4.7$$

where R is the set of real numbers.

For every feasible solution in decision space, there is an associated value for each objective. That is, the p-dimensional objective function maps the feasible region in decision space to the feasible region objective space $Z(X)$. More simply, if every combination of the decision variables that is defined as feasible by the problem constraints (ie., is feasible in decision space) is in turn inserted into the equations of the objective functions, the resulting values will define the feasible region in objective space. In practice, there will usually be an infinite number of feasible solutions in decision space. The corresponding feasible region in objective space can,

however, be identified in the case of a small problem, by inserting into the objective functions the values of the decision variables associated with the vertices of the feasible region in decision space (ie., where the constraint functions intersect). This will then locate the vertices of the feasible region in objective space.

In a strict sense, the term vector optimization is incorrect since it is not possible *a priori* to optimize a vector (Cohon and Marks, 1975; Goicoechea et al., 1982). That is, without a specified procedure by which to combine and compare objectives, a single optimal solution to the problem cannot be found. To find a single solution, information is required on the preferences that are held for the attainment of one objective relative to the preferences for the attainment of other objectives. If this type of preference information is known, a particular form of equation 4.4 could be specified which incorporates the measures of relative importance that are assigned to the achievement of specific objectives.

The concept of non-inferior solutions provides a basis for eliminating some solutions from further consideration, in the absence preference information. Identification of non-inferior solutions is based on the concept of Pareto optimality. More specifically, the vector x is a non-inferior solution if there exists no other vector x' such that:

$$z_k(x') \geq z_k(x) \quad \forall\ k = 1, 2, \ldots, p, \text{ and} \qquad 4.8a$$

$$z_k(x') > z_k(x) \quad \text{for some } k. \qquad 4.8b$$

where $Z_k(x)$ represents the value of each objective $k=1, 2, \ldots, p$.

The set of non-inferior solutions is alternatively referred to as Koopman's efficient set, the Pareto optimal set, or the transformation set, and is denoted here as $X*$. For every value of $X*$ in decision space, it has been noted previously, there is a corresponding value in objective space, as defined by the set of p objectives. This non-inferior set is denoted as $Z(X*)$. The non-inferior set is a subset of the feasible region in both decision space and objective space:

$$X* \subseteq X, \text{ and} \qquad 4.9$$

$$Z(X*) \subseteq Z(X). \qquad 4.10$$

These concepts are illustrated using the following two-objective, two-decision variable problem:

$$\text{Max } Z(x) = [z_1(x), z_2(x)], \text{ where}$$

$$z_1(x) = 3x_1 - x_2, \text{ and}$$

$$z_2(x) = -x_1 + 2x_2,$$

subject to:

$$g_1(x) = -x_1 + x_2 - 6 \leqslant 0,$$
$$g_2(x) = x_1 + x_2 - 8 \leqslant 0,$$
$$g_3(x) = x_1 - x_2 - 4 \leqslant 0,$$
$$g_4(x) = x_1 - 5 \leqslant 0,$$
$$g_5(x) = x_1 \geqslant 0, \text{ and}$$
$$g_6(x) = x_2 \geqslant 0.$$

Figures 4.1 and 4.2 show, respectively, the feasible region in decision space and the feasible region in objective space. By applying the definition of non-inferiority, as expressed by equation 4.8, the non-inferior set $Z(X*)$ was identified and is represented in Figure 4.2 by the cross-hatched line. Because the corner points with objective values in the non-inferior set (ie., $Z(x_3)$, $Z(x_4)$ and $Z(x_5)$) are also in the non-inferior set $X*$, the set of non-inferior solutions in decision space can easily be identified for this simple example.

At this point it is worth noting that the set of non-inferior solutions is essentially equivalent to multiple optima in single-objective programming models. In each case, the solutions represent alternative options in resource use that achieve the same level of attainment with respect to the decision criteria.

Although the total number of feasible solutions to

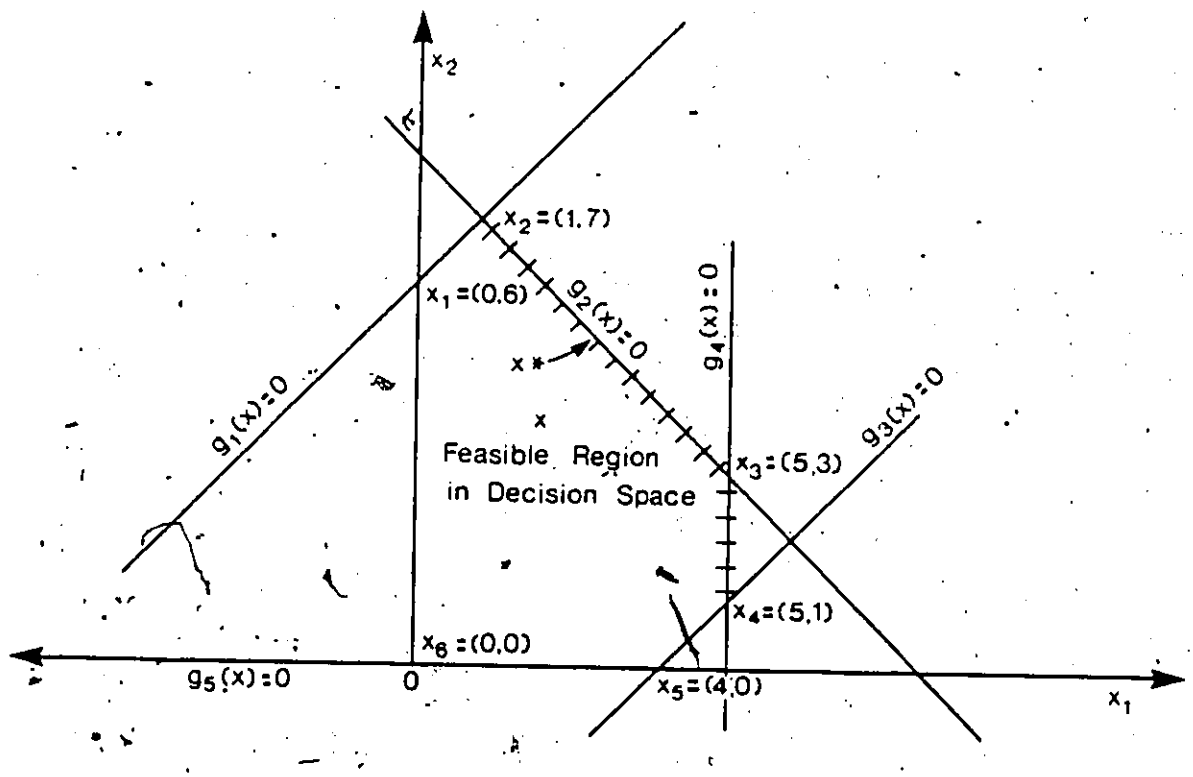


Figure 4.1 Feasible Region and Set of Non-Inferior Solutions in Decision Space.

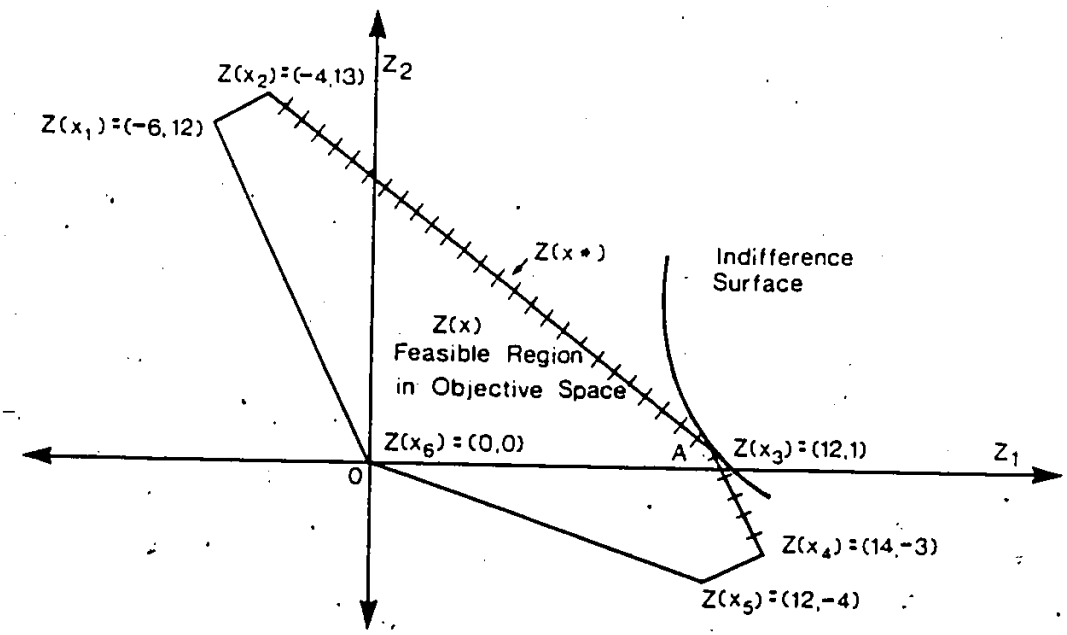


Figure 4.2 Feasible Region and Non-Inferior Set in Objective Space and Best Compromise Solution.

be considered may be reduced in light of the non-inferiority criterion, there is no formal basis for choosing between alternatives that comprise the non-inferior set. A single solution to the vector optimization problem, it was noted above, can only be found by introducing information on the preferences held with respect to the attainment of one objective relative to the preferences for achievement of the other objectives. For the purpose of diagrammatic representation, the relative preferences for achievement of specific objectives are represented in Figure 4.2 by an indifference surface. The preferred alternative is at the point of tangency of the highest attainable indifference surface with the feasible region, point A in Figure 4.2. Belenson and Kapur (1973) coined the term "best compromise solution" to identify this point, and Cohon and Marks (1975) note that this terminology is preferable to "optimal solution", as it connotes that the solution can only be considered optimal in terms of a particular set of value judgements. Alternative solution techniques in multiobjective analysis are distinguished by the way in which this preference information is expressed and incorporated into equation 4.4.

4.3.2 Multiobjective Solution Techniques

With the proliferation of multiobjective programming methods, it is not surprising that several attempts have been made to group techniques according to their similar characteristics (see, for example, Goicoechea et al., 1982; Loucks, 1975; Nijkamp, 1980; Roy, 1971). Two major categories of methods can be distinguished; generating techniques and techniques which rely on the articulation of preferences.

Generating methods were among the first multiobjective solution techniques developed. A generating method is utilized to identify the set of non-inferior solutions, X*, and the non-inferior set Z(X*). The feasible region of the problem is defined by the constraint set and the subset of non-inferior solutions is identified in relation to a vector of objective functions. No attempt is made to account for the preferences of decision makers in terms of levels of achievement for the specified objectives.

Willis and Perlack (1980) believe that an important function of multiobjective analysis is to illuminate the trade-offs associated with alternative solutions to a specific problem. In this respect, generating techniques have been reviewed favourably, since they provide all of the information one can obtain from a multiobjective model

in the absence of preferences (Cohon and Marks, 1975; Solomon and Haynes, 1984; Willis and Perlack, 1980). In addition to the identification of the non-inferior solutions in decision and objective space, Willis and Perlack (1980) note that the shadow prices provide a measure of the trade-offs among objectives for the non-inferior solutions. If the number of objectives is less than 4, the problem can be portrayed graphically, as in Figures 4.1 and 4.2, thereby facilitating interpretation by the decision maker.

Applications of generating methods have primarily been in the area of water resources planning (Cohon and Marks, 1973; Miller and Byers, 1973). Other applications include the use of generating methods to assist in power plant siting decisions (Cohon et al., 1980; Solomon and Haynes, 1984).

Difficulties with generating techniques are usually encountered with an increase in the number of objectives beyond 3. The number of solutions required to identify the non-inferior set is, for most generating methods, an exponential function of the number of objectives (Cohon and Marks, 1975; Willis and Perlack, 1980). Consequently, there may be an information overload in terms of the number of alternatives generated. Additionally, the ability to graphically display the trade-offs is lost when there are more than 3 objectives.

When there are three or less objectives, these generating methods may represent an appropriate framework within which to identify alternative resource development strategies and develop an awareness of goal relationships. The fact that generating methods are not particularly useful once the number of objectives exceeds three and the considerable potential for information overload leads to the conclusion that these methods are not well-suited as a general methodology for resource assessment.

Techniques within the second category, those that rely on the articulation of preferences for specific objectives, differ from generating techniques in that they attempt to identify a single solution. This requires information on the preferences held for the attainment of one objective relative to all others. A procedure is then required by which this preference information is incorporated into a function of the form represented by equation 4.4, such that the various objectives can effectively be combined. Given that this will be possible, a single solution (or perhaps multiple solutions) will then be identified from the set $Z(X*)$.

One approach relies on the identification of a set of weights that express the relative value attributed to the attainment of the respective objectives. If these weights are known, the optimization problem can be represented as:

$$\max\ Z(X) = \sum_{k=1}^{p} w_k^* Z_k(x), \qquad 4.11$$

subject to:

$$x \in X, \qquad 4.12$$

where w_k^* is a vector of optimal weights (Cohon and Marks, 1975).

Criticisms of these methods focus on the nature and reliability of the preference information elicited. Ignizio (1982), for example, questions the ability to develop credible numerical weights, particularly in public decision making when economic values must be related to social, aesthetic and human values. Hence, although technically it is a relatively easy matter to specify the multiple-objective function on the basis of numerical weights, its interpretation and the interpretation of the solutions generated is unclear.

An alternative approach to expressing relative preferences for the attainment of specific goals is to rank the goals in order of priority, rather than applying numerical weights. Ranking the goals in order of priority is believed to be less abstract and less ambiguous than determining a numerical value scheme. For this reason, multiobjective solution procedures based on a priority ordering of goals are preferred for resource assessment. A multiobjective programming method that is based on priority ordering of goals is goal programming. The following

section describes this method in greater detail.

Before discussing goal programming, it is appropriate to note that several classifications of multiobjective solution procedures list as a third category of techniques those that are based on a progressive articulation of preferences. These are iterative methods in that they involve determining a solution to the programming problem, presenting the solution to decision makers, soliciting their responses to the solution, and then modifying the problem in accordance with the observations made by the decision makers (Goicoechea et al., 1982). Modifications typically involve re-specifying the relative preferences for objective function achievement (Cohon and Marks, 1975). The procedure continues until the solution generated is considered to represent an acceptable compromise in terms of the achievement of the various objectives.

Although specific solution procedures have been developed which facilitate this iterative type of analysis (Cohon and Marks, 1975; Goicoechea et al., 1982), the essential difference between these methods and other multiobjective solution techniques that include preference information is procedural rather than in the nature of the technique itself. Any method could be applied in a similar iterative manner, including those reviewed in Chapter 3.

While the input of decision makers may be valuable

in undertaking resource assessment analysis, these iterative solution procedures are designed for a different analytical task than that under consideration here. Their primary function is to identify a single resource development strategy that represents an acceptable compromise in terms of development goals. Although resource assessment analysis is intended to provide guidance in this regard, the intention, as stated many times before, is not to determine via the method a specific resource allocation. The discussion now moves to a consideration of goal programming, which is a multiobjective solution procedure that is considered to be well-suited to resource assessment analysis.

4.4 GOAL PROGRAMMING

4.4.1 Technical and Theoretical Considerations

In terms of the classification of multiobjective programming solution techniques described above, goal programming is a member of the second class, a method which relies on the articulation of preferences. All objectives in goal programming are expressed as targets, and the best compromise solution is that which minimizes the deviations from these targets. Several different measures of goal achievement can be utilized in goal programming. The

following alternatives might be considered:

1. Minimize the sum of goal deviations;
2. Minimize the sum of the weighted goal deviations;
3. Minimize some non-linear form of the goal deviations;
4. Minimize the maximum goal deviations;
5. Minimize the goal deviations in order of priority; or
6. Some combination of the above;

The form adopted in this study, commonly referred to as pre-emptive goal programming, is based on the fifth alternative listed above and requires that for a set of ordered goals, higher ranked goals must be satisfied before those of lower priority are considered. The technique allows for deviation variables from two or more goals to be ranked at the same priority level, so long as they can be expressed in common units. The analyst also has the option of assigning numerical weights to express the relative preferences for deviation variables represented at each priority level.

Following Ignizio (1982), the general goal programming model is represented as:

$$\text{lexicographically min. } Z = [g_1(d^+, d^-), \ldots, g_r(d^+, d^-)], \quad 4.13$$

subject to:

$$x \in X, \qquad 4.14$$

$$f_i(x) + d_i^- - d_i^+ = T_i, \qquad 4.15$$

$$x_j, \; d_i^+, \; d_i^- \geq 0, \qquad 4.16$$

where $f_i(x)$ is a goal constraint i, expressed as a function of the decision variables $x = (x_1, x_2, \ldots, x_n)$,

X is the feasible region from which the vector x must be chosen,

T_i is the target for goal constraint i,

d_i^+ and d_i^- are, respectively, the positive and negative deviations from target T_i,

d^+ and d^- are vectors of the positive and negative deviation variables, and

g_r represents a linear function of the deviation variables at priority level r.

The vector z is a lexicographic minimum if there exists no other vector z' such that at priority r,

$$z'_r < z_r, \qquad 4.17$$

when all other higher ranked elements $(z_1, \ldots z_{r-1})$ are equal.

Since this study is concerned exclusively with the development and use of a linear model, $f_i(x)$ is given as:

$$f_i(x) = c_{ij} X_j \quad , \qquad 4.18$$

where c_{ij} is the technical coefficient associated with variable j in goal or constraint i.

For any paticular goal, there are three possible, mutually exclusive outcomes: 1. The target level is exactly achieved; 2. There is a negative deviation from the target; or 3. There is a positive deviation from the target. A useful characteristic of goal programming is that the method offers considerable flexibility in the manner in which goals are expressed, since the deviation variables for a specific goal can be combined in the objective function in several different ways. In some instances, for example, exact achievement of the target level may be desired, in which case both the positive (d_i^+) and negative (d_i^-) deviation variables would be incorporated into the objective function at the same priority level. Alternatively, minimization of the negative deviation from a target level may be of greater importance than minimizing the positive deviation. In the case of an employment goal, for example, minimizing under-achievement of the target may be of greater importance, while over-achievement would be of less, or perhaps no, concern. The positive deviation variable could then be assigned to a lower priority level or, if there is no concern with over-achievement, could be

excluded from the objective function altogether. Conversely, for some goals it may be desirable to minimize over-achievement of a target, while achievement levels that are below the target value would be acceptable. For goals that relate to environmental quality, for instance, the target may represent an environmental quality standard. The primary concern would be to avoid exceeding the specified standard, while pollution levels below the standard would be quite acceptable. The positive deviation variable would then be included in the objective function, while the negative deviation variable was excluded.

The goal programming framework also allows for maximization and minimization of goal functions. The most straightforward approach to maximization is to set the target level to a value known to be unattainable and minimize the corresponding negative deviation variable. Similarly, minimization is achieved by setting the target level to a value known to be sufficiently low that it cannot be attained, and minimize the appropriate positive deviation variable.

Facilities for sensitivity analysis in goal programming are similar to those for linear programming and include (Ignizio, 1982):

1. Changes in the values of the right-hand-sides of goals or constraints (T_i's);
2. Changes in the coefficients associated with

the goals or constraints (c_{ij}'s);

3. The addition or removal of a goal or constraint;
4. The addition or removal of a decision variable;
5. A re-ordering of the goal priorities; and
6. Changes in the numerical weights associated with goal deviation variables.

Goal programming is conceptually similar to the goals achievement matrix, discussed in Chapter 3, and embodies some of the same desirable characteristics in terms of a methodology for resource assessment. Specifically, the technique provides for the assessment of resource development proposals in relation to multiple evaluation criteria. This is consistent in part with the requirements of a resource assessment methodology. The important advantage goal programming has over the GAM and other plan evaluation techniques is that the technique does not require the prior specification of resource allocation alternatives. The model itself will allocate resources in a manner that best satisfies the conditions specified in the model. Goal programming, therefore, has the capability to address the first question pertinent to resource assessment analysis in that it can be used to generate a resource allocation pattern which best satisfies the goals listed.

Although single-objective programming frameworks can

also be used to identify alternative resource allocations, the goal programming model offers significant advantages in terms of the capability to account for multiple goals. The manner in which goals are expressed in the goal programming framework are very similar to the regular constraints of a single-objective programming model. The important distinction, however, is that in goal programming a solution will be generated even if the specified target cannot be achieved. This is not the case when a constraint cannot be satisfied in a single-objective programming model (see Section 4.2.5). Consider the previous example of an employment goal for which the primary concern is to minimize the negative deviation from the specified target. Even if the target cannot be achieved, a solution will be generated, which will indicate the extent to which employment falls short of the target level. This characteristic of goal programming provides useful opportunities to explore both the nature and extent of goal conflicts, a capability which will be demonstrated subsequently.

As stated in the Introduction, uncertainties often exist in terms of production relationships, resource constraints, and the institutional framework within which resource developments will take place, and an important consideration relates to the effects of varying assumptions in the model with respect to these conditions.

Additionally, different perceptions will exist in terms of the importance attributed to the various development goals, leading to the question concerning the effects upon resource assessments of changes in the relative importance assigned to development goals. From this emerged the question as to whether goals were in conflict and, if so, to what extent. Further essential requirements of a resource assessment methodology are, therefore, that the implications of these uncertainties can be addressed and that there exists the facility to perform resource assessments from different perspectives relating to the importance of individual development criteria.

The various opportunities for sensitivity analysis in goal programming provide automated facilities for addressing these concerns that are fundamental to resource assessment. Different assumptions regarding production relationships and resource constraints can be incorporated via the methods described in 1-4 above. Alternative perceptions regarding the relative importance of development goals can be investigated through methods 5 and 6. Since solutions to goal programming problems will indicate the extent to which individual goals can be attained, re-specifying priority orderings of goals will also provide a systematic basis for identifying goal conflicts.

A further desirable characteristic of goal

programming is that the need to determine numerical value weights can be avoided. The difficulties associated with identifying valid numerical weighting schemes have been alluded to previously. Although the goal programming model, as it has been defined above, allows for numerical weights to be incorporated, the problem of specifying valid numerical weights can be circumvented by exclusively using a priority ordering system to express preferences of the achievement of the individual goals. Expressing preferences in this manner is less abstract and less ambiguous than determining a numerical value scheme.

Considerable caution must be exercised, however, in soliciting preference information from decision makers. Although a goal programming model based entirely on a priority ranking of goals does not require a statement of numerical weights, the model is, in fact, based on the most extreme weighting, a zero-infinity weighting system. The possible implications of ranking one goal higher than another must be clearly articulated to decision makers.

The target levels specified for individual goals will have an important effect on the solution generated. This and other aspects of goal programming are illustrated through a simple numerical example. Two competing land use activities, X_1 and X_2, are assumed. From each land use, a different commodity is produced. To produce one unit of each commodity requires one unit of land, and the total

amount of land in the region is limited to 80 units. Development goals refer to the amount of each commodity produced. The production targets are 60 units from land use X_1 and 40 units from land use X_2. For every unit of land devoted to X_1, 2.4 people are employed, while 2 people are employed for each unit of land devoted to X_2. A target of 240 people employed has been set. Pollution is generated by each of the land use activities. Land use X_1 will generate 7 units of pollutant per unit of land developed and land use X_2 will generate 3 units of pollutant per unit of land developed. To maintain environmental quality, the total amount of pollution should not exceed 210 units. Regional representatives have indicated that the highest priority is employment, followed in order by the goals relating to production from X_1, production from X_2, and environmental quality.

The problem is expressed mathematically as:

$$\text{lex. min. } [(d_1^-), (d_2^-), (d_3^-), (d_4^+)],$$

subject to:

$$X_1 + X_2 \leq 80 \quad \text{(Land availability)},$$

$$2.4X_1 + 2.0X_2 + d_1^- - d_1^+ = 240 \quad \text{(Employment)},$$

$$X_1 + d_2^- - d_2^+ = 60 \quad \text{(Production } X_1\text{)},$$

$$X_2 + d_3^- - d_3^+ = 40 \quad \text{(Production } X_2\text{)},$$

$$7.0X_1 + 3.0X_2 + d_4^- - d_4^+ = 210 \quad \text{(Pollution), and}$$

$$X_1,\ X_2,\ d_i^-,\ d_i^+ \geq 0.$$

The sample problem is represented graphically in Figure 4.3. Deviation variables included in the objective function have been circled. The constraints define the feasible space and the first priority goal is considered, which is to achieve a target of at least 240 people employed. This target cannot be achieved with the available resources. The model seeks to minimize the deviation from the target level, and this will occur at point A. All of the land available is devoted to use X_1. Any re-allocation of land to use X_2 would result in a larger negative deviation from the employment target. For this problem, the solution has been determined entirely by the first priority goal.

Substituting $X_1=80$ and $X_2=0$ into the model yields the solution reported in Table 4.1. The minimum value of the deviation variable from the employment target that can be achieved is 48, which means that 192 persons are employed under this resource allocation pattern. Production from land use X_1 exceeds the targeted value by 20 units, while there is a shortfall in production from X_2 of 40 units. The resource allocation under this scenario results in a pollution level that exceeds the target value by 350 units.

For a second example, the employment target is

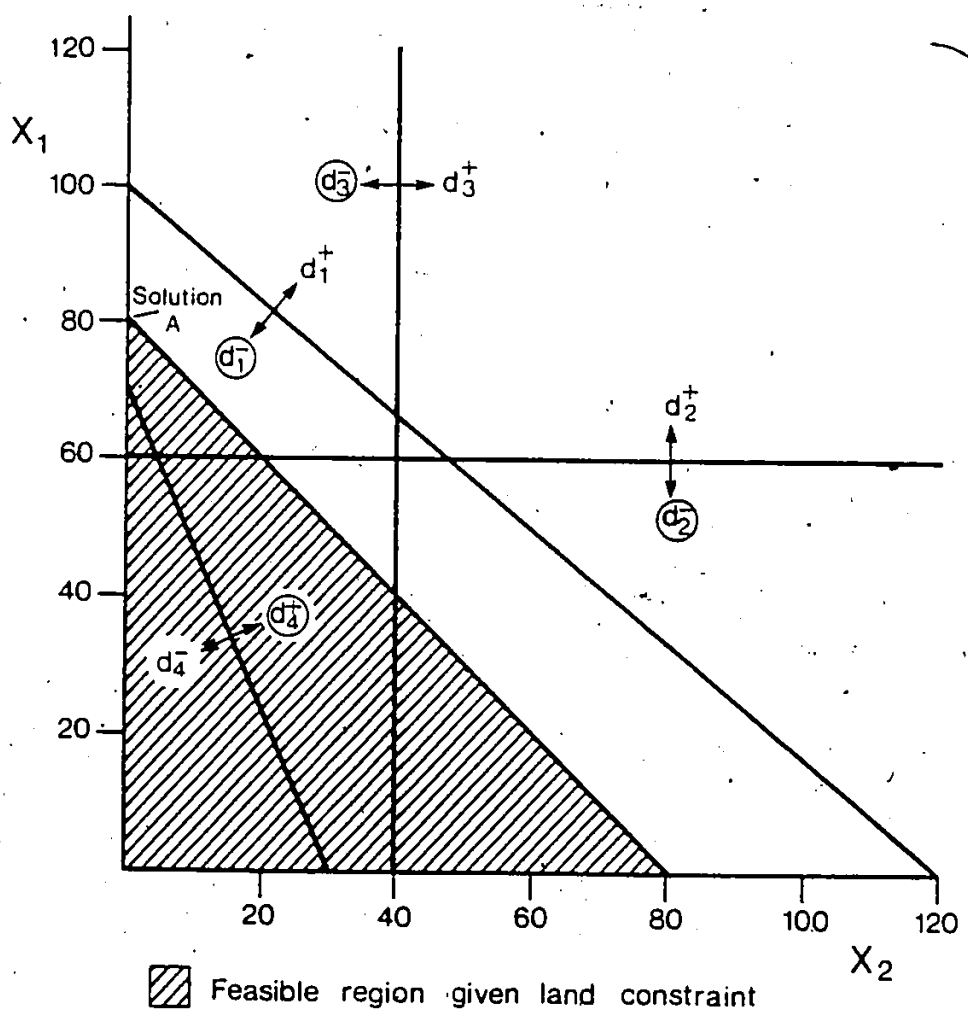


FIGURE 4.3 Goal programming sample problem: Graphical representation A

TABLE 4.1

GOAL PROGRAMMING SAMPLE PROBLEM:
SOLUTION 1

Goal Description	Target Level	Priority Level	Level of Goal Attainment	Deviation
Employment	240	1	192	-48
Production X_1	60	2	80	+20
Production X_2	40	3	0	-40
Pollution	210	4	560	+350

reduced to 150 people employed, and the goal is expressed as:

$$2.4X_1 + 2.0X_2 + d_1^- - d_1^+ = 150.$$

In all other respects the model is unchanged. This revised problem is represented in Figure 4.4. The employment goal can now be satisfied with the available resources. The second priority goal, production from land use X_1, is then considered. The target level of 60 units can also be achieved with the available 80 units of land. In fact, production of X_1 may be as high as 80 units without adversely affecting the first priority goal or violating the land constraint. Since the second priority goal is attainable, the production target for X_2 is considered. By allocating 60 units of land to X_1, 20 units can be produced from X_2, which is only half the targeted value. Any further increase in X_2, however, would result in a decrease in production from X_1 below the target amount, which is not permissable. The solution to this problem is at point A.

The values X_1=60 and X_2=20 are substituted into the equations of the model and the results are reported in Table 4.2. Comparison of Tables 4.1 and 4.2 reveals that a lowering of the target level for the highest priority goal results in a quite different solution to the programming problem. The employment target is now exceeded, with a

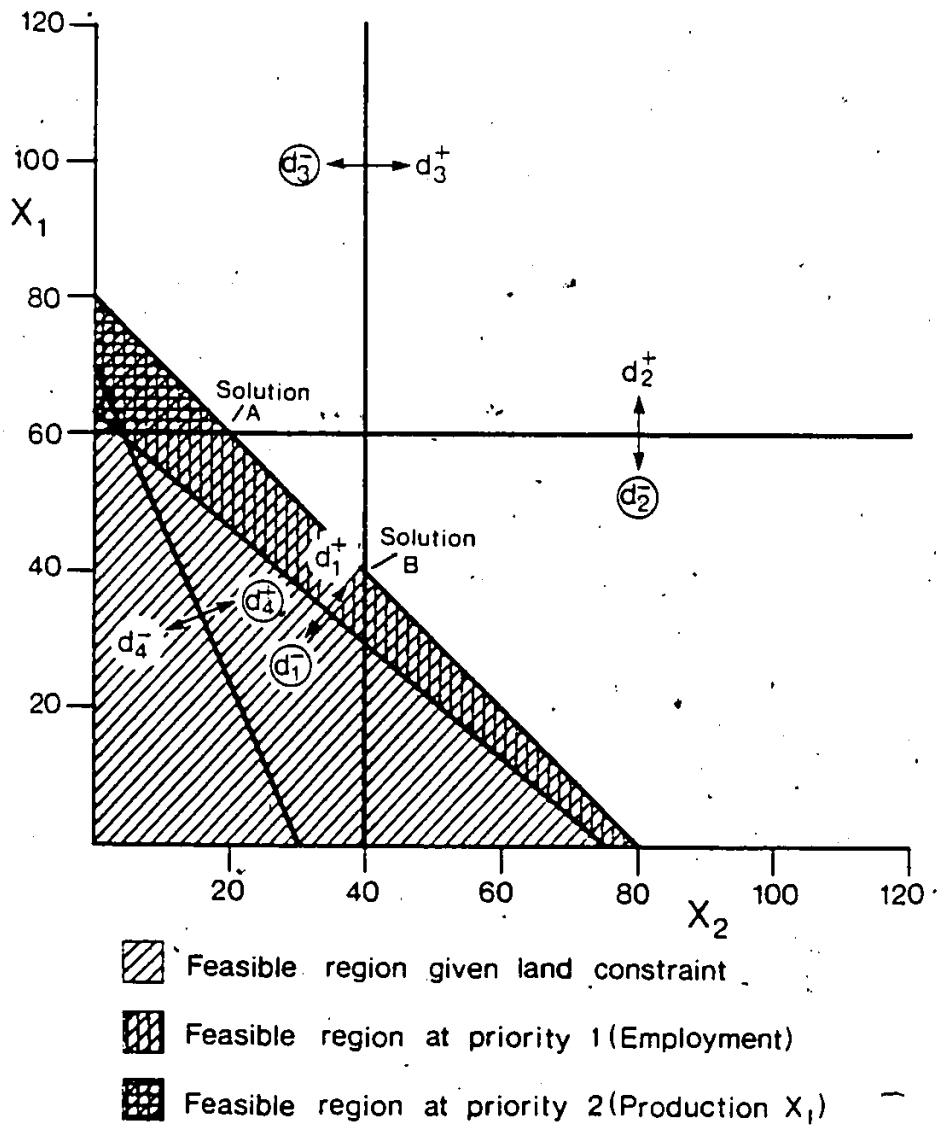


FIGURE 4.4 Goal programming sample problem: Graphical representation B

TABLE 4.2

GOAL PROGRAMMING SAMPLE PROBLEM:
SOLUTION 2

Goal Description	Target Level	Priority Level	Level of Goal Attainment	Deviation
Employment	150	1	184	+34
Production X_1	60	2	60	0
Production X_2	40	3	20	-20
Pollution	210	4	480	+270

total of 184 persons employed. Note, however, that this is less than the employment level obtained in the first example. Production from X_1 is exactly at the target level, and 20 units less than obtained previously. Production from X_2, however, has increased by 20 units, leading to an improvement with respect to that goal. There is also an improvement in terms of the pollution goal, for which the target is now exceeded by 270 units.

A third scenario is considered in which it is assumed that land uses X_1 and X_2 now both have employment coefficients of 2.0, and the employment target is again set at 240. The employment goal is now represented as:

$$2.0X_1 + 2.0X_2 + d_1^- - d_1^+ = 240.$$

Other aspects of the model remain the same. Figure 4.5 is the graphical representation of this problem. As in the first case, the employment goal is unattainable. Note, however, that in this revised problem, all combinations of land uses X_1 and X_2 that are represented by the land constraint will have the same result in terms of the employment goal. In other words, multiple optima exist at the first priority level of the model. The minimum value of d_1^- that can be achieved is 64 (176 people employed), and this is invariant with respect to changes in the land use allocation. Given this, the second priority goal can be

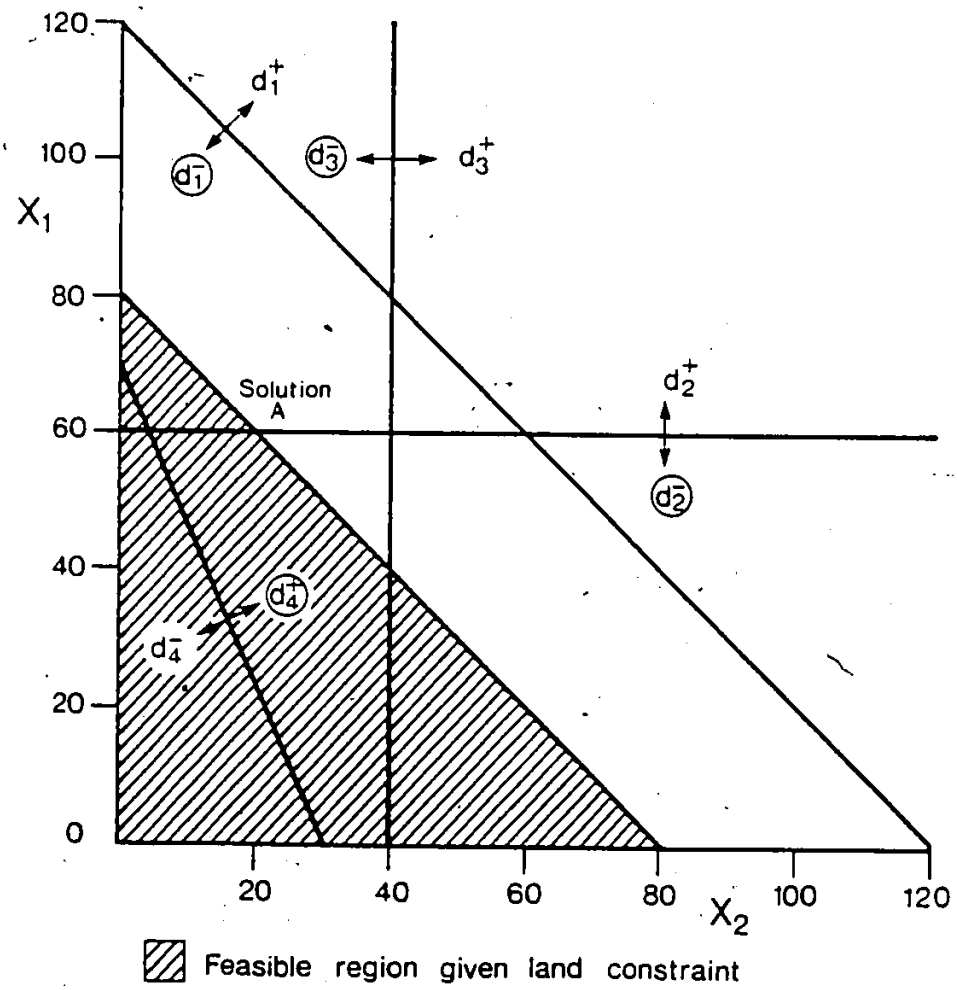


FIGURE 4.5 Goal programming sample problem: Graphical representation C.

considered. An allocation of 80 units to X_1 would satisfy the second priority goal, while simultaneously minimizing the negative deviation from the employment target. Since the second priority target is satisfied, the third priority goal can be considered. At point A, the negative deviation from the first priority goal is still minimized, the second priority goal is satisfied, and the negative deviation from the third priority goal is also minimized. The solution is identical to that of the second example, except that there is a negative deviation of 64 units from the employment target. In this example, note also that the solution would not change if the employment target was lowered.

Results of the analysis of this simple problem suggest that target setting is an important consideration in model formulation. The question then arises as to how target levels for the goals are established. In some instances, decision makers may be prepared to specify desired achievement levels for the respective goals. The adoption of a goal programming model may, in fact, encourage decision makers to be forthcoming with statements of target levels when targets may otherwise be imprecisely defined. In practice, however, it may prove very difficult to elicit this information. In such cases, there are other alternatives available to the analyst. One approach is to specify as targets some minimum or maximum acceptable goal level, from which only positive or negative deviations,

respectively, would be permitted. As an alternative approach, goals might be expressed in such a way that the model will minimize or maximize the achievement level. Combining the latter two approaches, minimum or maximum acceptable levels could be specified and the goals respectively maximized or minimized beyond the specified minimum or maximum levels. Regardless of whether target levels are specified by decision makers or defined in some other manner, investigating the sensitivity of the solution to adjustments in the target levels will be of considerable importance.

This sample problems also provide some insight as to how goal programming can be used to identify and assess goal conflicts. From the examples above, it is apparent that the best solutions with respect to the employment goal also result in solutions that are good with respect to the production target for land use X_1. A further observation is that no more than half of the targeted production from land use X_2 is ever achieved. As the amount of land devoted to X_2 increases, though, results improve with respect to the pollution goal. These observations suggest that the employment goal and the goal relating to production from X_1 are compatible; but that these two goals conflict with targets on production from land use X_2 and concerns for environmental quality.

These observations can be verified if the priorities

for production from land use X_1 and for production from X_2 are reversed. The objective function of the problem is re-written as:

$$\text{Lex. min. } [(d_1^-), (d_3^-), (d_2^-), (d_4^+)].$$

The employment goal considered is:

$$2.4X_1 + 2.0X_2 + d_1^- - d_1^+ = 150,$$

with the remainder of the problem as stated originally. Figure 4.4 is an appropriate graphical representation of the problem, apart from the shading of the feasible regions. For this problem, the solution is at B, with 40 units of land allocated to each of X_1 and X_2. Inserting these values for the decision variables into the model, the results reported in Table 4.3 are derived. Comparing these results to those of Table 4.2, the expected result of the priority change is an improvement with respect to the target on production from X_2 and the pollution goal, and inferior solutions in terms of the employment goal and the production goal for X_1.

In this simple problem, these conflicts can easily be identified in the mathematical statement. In larger and more complex problems, however, goal conflicts may not be apparent from the statement of the problem, and goal

TABLE 4.3

GOAL PROGRAMMING SAMPLE PROBLEM:
SOLUTION 3

Goal Description	Target Level	Priority Level	Level of Goal Attainment	Deviation
Employment	240	1	176	-64
Production X_1	60	3	40	-20
Production X_2	40	2	40	0
Pollution	210	4	400	+190

programming analyses can provide useful insights into conflicts between goals.

4.4.2 Resource Management Applications

In the private sector, the entrepreneur has command of the operating system and usually has a clear conception of management objectives and targets. For this decision environment, goal programming is a particularly appropriate tool. Not surprisingly, therefore, goal programming models have found extensive application in business management. The structure and assumptions of goal programming defined this technique as being particularly well-suited to a private sector decision environment increasingly characterized by a multiplicity and diversity of goals (Lee, 1972).

The role of goal programming in public sector planning has been questioned, primarily on the basis of whether development targets can be satisfactorily identified (Cohon and Marks, 1975; Dyer et al., 1979). Goal programming has been applied extensively to public sector planning problems, however, with generally favourable reviews. There have been applications to forest (Dane et al., 1977; Schuler et al., 1977), agricultural (Cortes, 1981), and recreation (McGrew, 1975) resource planning, and to industrial (Charnes et al., 1977; Werczberger, 1976) and

residential (Courtney et al., 1972) location problems.

A multiple land use allocation model, designed by Dane et al. (1977) to assist with planning decisions for the Mount Hood National Forest in Oregon, provided useful information on:

1. The sensitivity of land allocations to combinations of planning goals;
2. Identification of the goal constraints that had the greatest effect on model solutions;
3. Sensitivity of the allocations to goal priorities; and
4. The trade-offs between goals.

Similar types of information have been identified here as essential for resource assessment analysis. Schuler et al. (1977) have also testified strongly in favour of goal programming as a technique to assist resource management decisions, based on their application to a forest resource planning problem. They stress, though, the need to closely interact with decision makers, particularly in identifying goal priorities and target levels. Similar observations were made by Werczberger (1976), who noted considerable sensitivity of model solutions to target levels and the priority ordering of goals in his application of the technique to a hypothetical industrial location problem. These observations are consistent with

those made in the previous section in reference to the sample problem analyzed.

Despite some skepticism, therefore, goal programming has been applied with apparent success to a diverse range of public sector planning problems, including applications to resource management problems. Once its nuances are understood, the technique appears to have considerable potential as a resource assessment methodology. The capabilities of the technique as a resouce assessment method will be further evaluated in an application to the Eastern Ontario forest energy project.

4.5 SUMMARY

A desirable characteristic of programming models is that they may be used to address a variety of research questions. Some applications, for example, have involved the use of programming models to simulate the possible repercussions of proposed developments. In other applications, programming models have been used to identify a "best" alternative, which then represents a target to which policy is directed. Applications of the first type are a response to research questions that are quite different from those under consideration here. The search for a single solution, which is characteristic of the second type of analysis, is also inconsistent with the type

of resource assessment proposed here.

More recently, programming models have been used to generate a set of alternative resource allocation plans. Within this context, the models have also proved useful in investigating the extent to which allocation patterns may be sensitive to resource availability, input-output combinations, economics, development priorities and a wide variety of other technical, socio-economic, environmental and political factors. In this sense, optimization techniques are not intended to replace decision makers, but instead to provide a framework for analyzing and evaluating the complex interdependencies typically associated with public sector development problems. The single-objective model provides a poor basis for analysis, however, when there is an explicit concern for multiple and possibly conflicting goals, expressed in disparate metrics.

Recognition of the fact that both private and public sector decisions are more often characterized by multiple and often incommensurate goals has led to research into the development of programming techniques with the capability to account for multiple objectives. Among the numerous multiobjective programming techniques that have been specified, goal programming is one that is recognized as having considerable potential as a resource assessment methodology.

The technique offers the opportunity to generate a

set of alternative resource allocation patterns according to different goal priority orderings and target levels. Additionally, model solutions can be used to identify conflicts between goals and the trade-offs that exist. The capability to incorporate multiple and perhaps conflicting goals, expressed in incommensurate units, is a desirable feature, given the variety of concerns that characterize resource development projects. The various facilities for sensitivity analysis in goal programming permit further analysis relating to the relationships between goal attainment, resource limitations and model coefficients.

In the following chapters, a resource assessment system, based on a goal programming model, is developed and applied to the forest energy project in Eastern Ontario. This application provides a further basis on which to evaluate the technique as a resource assessment methodology.

CHAPTER 5

THE RESOURCE ASSESSMENT MODEL

5.1 INTRODUCTION

The potential for hybrid poplar plantations to supplement Ontario's energy supply system, particularly in the Eastern region, is widely recognized. Extensive research on poplar culture and management has insured that biomass plantations can be successfully developed. The regional impacts of hybrid poplar-based resource developments are not as well understood, however. In particular, concerns relate to the economics of biomass production and energy conversion, net energy gains, environmental quality, and regional employment and income generation.

An important question relates to the potential for hybrid poplar plantations to achieve specified goals, given available resources and development priorities. The implications of varying assumptions with respect to resource limitations, production relationships and institutional restraints should also be investigated. Analysis directed at these questions is referred to here as

resource assessment, in this case with specific reference to a renewable energy project, and goal programming appears to be a suitable methodology for such investigations.

The application of a goal programming model to assess hybrid poplar developments serves two purposes in this research. First, it provides the opportunity to evaluate the suitability of goal programming for resource assessment analysis within an applied context. Second, application of the model is expected to provide useful insights into the potential regional implications of forest energy plantation developments in Eastern Ontario.

The following section provides information on the Eastern region of Ontario, where future development of hybrid poplar plantations on a large scale is most likely to occur. Mathematical specification of the resource assessment model and the presentation of data bases constitutes the final major section of the chapter.

5.2 THE REGIONAL SETTING

Eastern Ontario is that region of the province east of Peterborough and south of Algonquin Provincial Park. More specifically, the boundaries can be defined as those of the Ontario Ministry of Natural Resources Eastern Region (Figure 5.1). The current study is concerned only with the

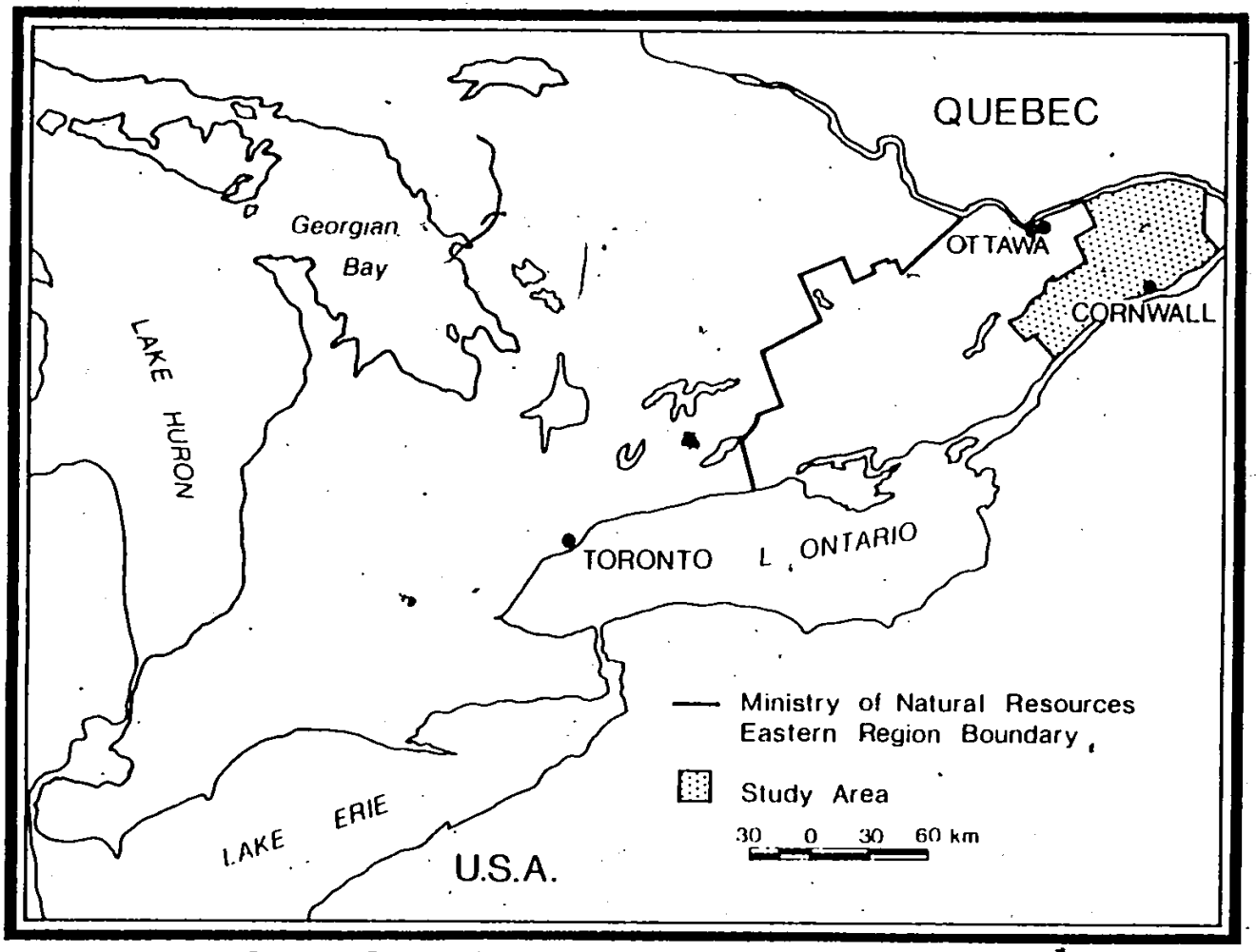


Figure 5.1 The Ontario Eastern Region and Location of the Study Area.

six eastern-most counties, an area within which large-scale development of forest energy plantations is likely to occur. Recently, an extensive forestry and agricultural resource inventory of the area was completed (Ontario Ministry of Agriculture and Food (OMAF) and Ontario Ministry of Natural Resources (OMNR), 1982) as part of a regional development initiative. This inventory provides reliable estimates of land available for biomass energy plantations. Although the study is concerned with only a part of the Eastern region, the comments of this section are often relevant to all of Eastern Ontario.

The physical landscape is largely a product of glacial action during the Pleistocene Ice Age. The region is part of the St. Lawrence Lowlands, an area characterized by flat-lying but gently undulating Paleozoic strata (OMAF and OMNR, 1982). To the north and west, the region is bordered by the Canadian Shield, while the Appalachain Mountains lie to the south and east.

In the eastern-most region, the soils are predominantly clays (Figure 5.2). Poor drainage in these soils is an impediment to agriculture, but when the drainage is improved, these clay soils are well-suited to farming (OMAF and OMNR, 1982). Loams and sands also occur throughout the region. A high water table in the sand plains contributes to drainage problems and these soils also have low fertility. Surface stoniness also causes

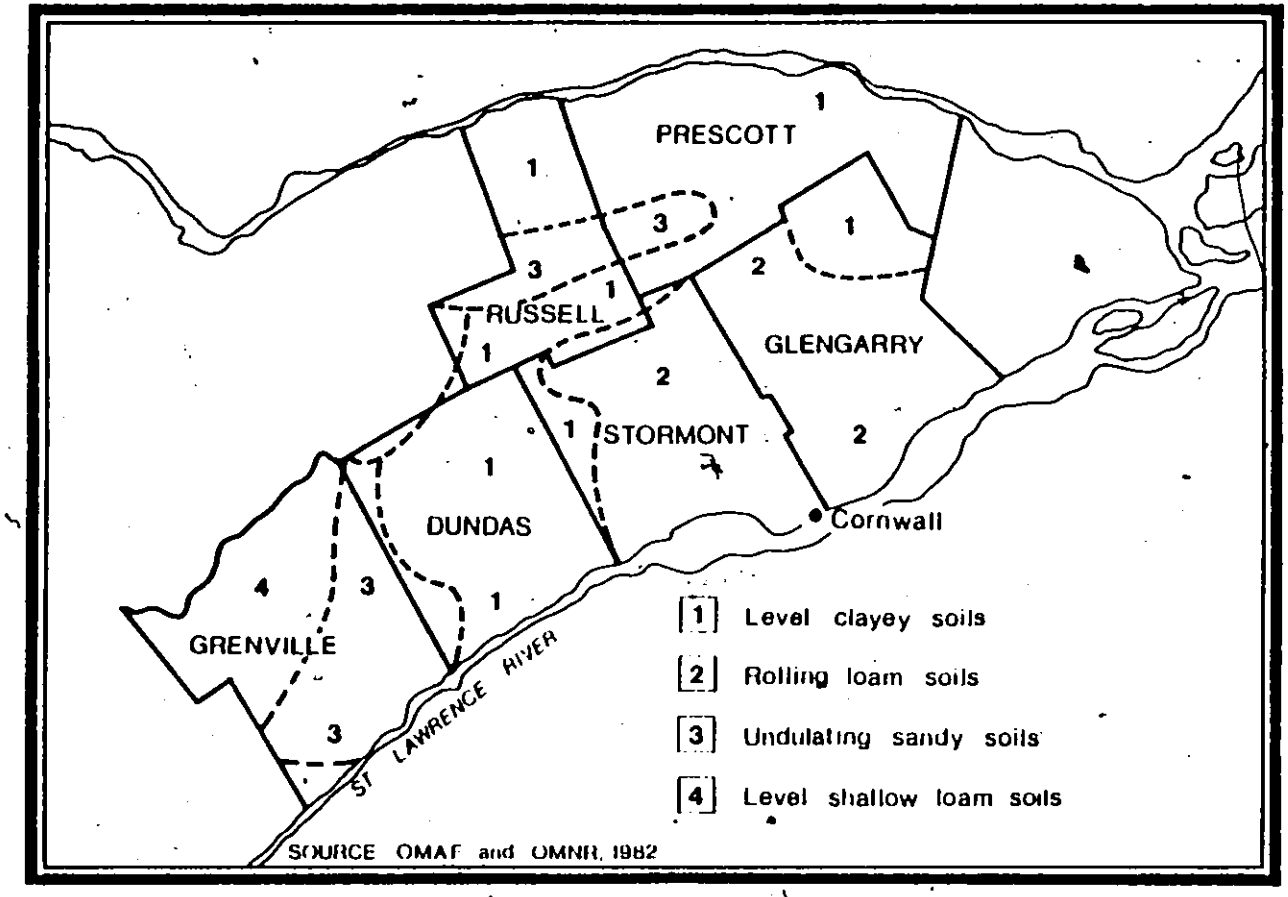


FIGURE 5.2 SOILS OF EASTERN ONTARIO

problems in cultivating the land (OMAF and OMNR, 1982).

The climate of Eastern Ontario is somewhat more severe than that of Southern Ontario. The mean daily temperature for January is -10C in Eastern Ontario, and slightly warmer at -5C in Southern Ontario (Brown et al., 1980). Summer temperatures are comparable for the two regions. The cooler temperatures in the Eastern region result in a growing season that is approximately 12 days shorter than that of Southern Ontario, beginning around April 15 and ending in late October, (Brown et al., 1980). Mean annual precipitation is approximately equal for Southern and Eastern Ontario, at about 90 cms. The poor soil drainage characteristics of Eastern Ontario means that there is often surface flooding.

The predominant agricultural activity in Eastern Ontario is dairying. Of the 9,700 farms enumerated in the region in the 1981 Census, almost 3,800 (29 percent) were reported as dairying operations. Eastern Ontario accounted for 27 percent of the total 1981 milk production in Ontario.

Hay, fodder and grain corn, barley and oats are the major crops grown in the region, accounting for more than 95 percent of the region's cropland. Acreages of these crops within the region have remained relatively stable over the last decade, with the exception of barley and grain corn. The latter have increased in acreage, to highs

in 1980 of 34,000 and 52,000 hectares, respectively (Land Evaluation Project, 1982). Annual production of crops has varied considerably over the last decade, with the most noticeable gains in the production of grain corn and barley. Soybean production has assumed greater importance in recent years, with more than 1,000 hectares being planted since 1979 (Land Evaluation Project, 1982).

Apart from the prominence of the region in terms of dairying, Eastern Ontario is not a major producer of agricultural products in Ontario. In 1981, the $4.4 million of farm sales from the region accounted for only 9.5 percent of total farm receipts in Ontario. Moreover, agricultural retrenchment has been a dominant trend within the region. Since 1966, the number of farms enumerated in Eastern Ontario has decreased from 18,665 to 14,532 in 1976 and 12,905 in 1981, a 30 percent decrease over the 15 year period. While this might in part be attributed to farm consolidation, there has been a corresponding decrease in total farm area, area of improved farmland, and the total area under crops (Figure 5.3). Increasingly, farmers are seeking off-farm work to supplement low incomes, particularly those with operations other than dairying (Pfeiffer, 1978).

Beattie et al. (1981) have described the area as one of retreating agriculture and for which the prospects of economically viable farms are limited. Farm consolidation

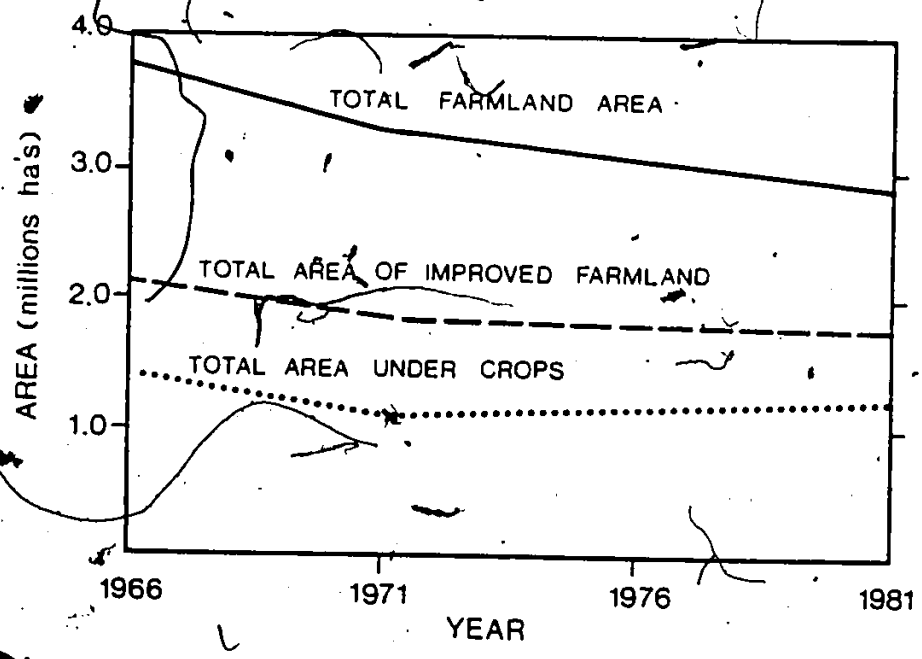


Figure 5.3 Area of Farmland, Area of Improved Farmland and Total Area Under Crops in Eastern Ontario, 1966-1981.

is believed to have contributed to the slowing of rates of agricultural decline in Eastern Ontario, but to improve economic circumstances in the rural areas, the promotion of activities in addition to agriculture will be necessary (Beattie et al., 1981).

The declining agricultural sector is symptomatic of the depressed economic and social circumstances throughout the region. In 1981, more than 7 percent of the working population within the region was unemployed, compared to a provincial average of 5.6 percent. This is a continuation of a long term trend (Wayman, 1978). Moreover, the unemployment problem is more serious than the figures would indicate, if the wide seasonal fluctuations are taken into consideration (Wayman, 1978). Wayman also notes that incomes have been declining as a percentage of the Ontario average, and that the proportion of people receiving social assistance is higher than the Ontario average.

The depressed social and economic conditions of the Eastern region are recognized as a major regional development problem within the province. In 1978/79, the provincial and federal governments initiated a cooperative development program in the region, named the Eastern Ontario Development Program, designed to improve the region's circumstances through the promotion of industry, agriculture and forestry. The program is jointly coordinated and funded by the federal Department of

Regional Industrial Expansion and the provincial Ministry of Treasury and Economics. Several other provincial ministries take an active part in the program, including the Ministry of Natural Resources, the Ministry of Agriculture and the Ministry of Industry and Tourism. Development of the region's natural resources is the major focus of the program, as reflected in the fact that natural resource development consumes 80 percent of the program's $50 million budget. A total of $9 million is provided for the development of forest resources.

The New Forests in Eastern Ontario program is an important component of the forestry development initiative. New Forests in Eastern Ontario was a five year program, initiated in 1978, intended to encourage the development of forest projects in the region (OMAF and OMNR, 1982). A fundamental component of the New Forests program was the promotion and development of hybrid poplar plantations.

Poplar plantations can be established on land not well-suited to agriculture and still be productive. Thus, plantations need not necessarily compete with existing land uses. Moreover, the opportunity to establish forest plantations and market the biomass may represent a useful income supplement to landowners. The establishment of biomass processing facilities, including those for the production of energy, may further contribute to regional economic development, through increased employment and the

generation of expenditures on local goods and services.

Regional economic development may serve as an impetus to the promotion of forest energy projects, but concerns exist beyond the contribution to employment and the regional economy. Economic viability in both the production of biomass and its conversion to useable energy, energy efficiency and effects on environmental quality were all identified in Chapter 2 as important additional factors that must be considered in relation to a regional biomass energy system.

Application of a goal programming system to analyze this resource development project will help to identify the potential hybrid poplar plantations offer for regional development. In addition, the analysis will assist in identifying possible conflicts between regional development priorities and the other development goals. The remainder of this chapter is devoted to describing the goal programming model that is used to address these questions.

5.3 A RESOURCE ASSESSMENT MODEL FOR HYBRID POPLAR DEVELOPMENTS

The purpose of the model described here is to identify the extent to which regional development goals for Eastern Ontario can be satisfied through the development of forest energy plantations and their eventual conversion to

useable energy. The model can also address the related questions of whether conflicts exist between development goals and what the effects are of varying assumptions in terms of input information.

To address these questions, a goal programming model has been designed to allocate land resources to biomass production and, simultaneously, to allocate biomass to end uses, such that a prioritized set of goals is best satisfied. The region has been defined as the six eastern-most counties of the province and is represented in detail in Figure 5.4. Available land within the region is allocated, at the township level, to biomass production under alternative management systems. The annual supply of biomass is simultaneously assigned to end uses, which include the co-generation of electricity and steam, methanol production and institutional heating. The quantity of biomass assigned to a particular end use determines the size and output capacity of the conversion facility. The future potential development site for all end uses is assumed to be the town of Cornwall.

Model output defines the spatial allocation of biomass production and end-use designations (in terms of both the types and sizes of conversion facilities), which together best satisfy a particular ordered set of goals, under the stated conditions. The level of achievement for each goal is also provided.

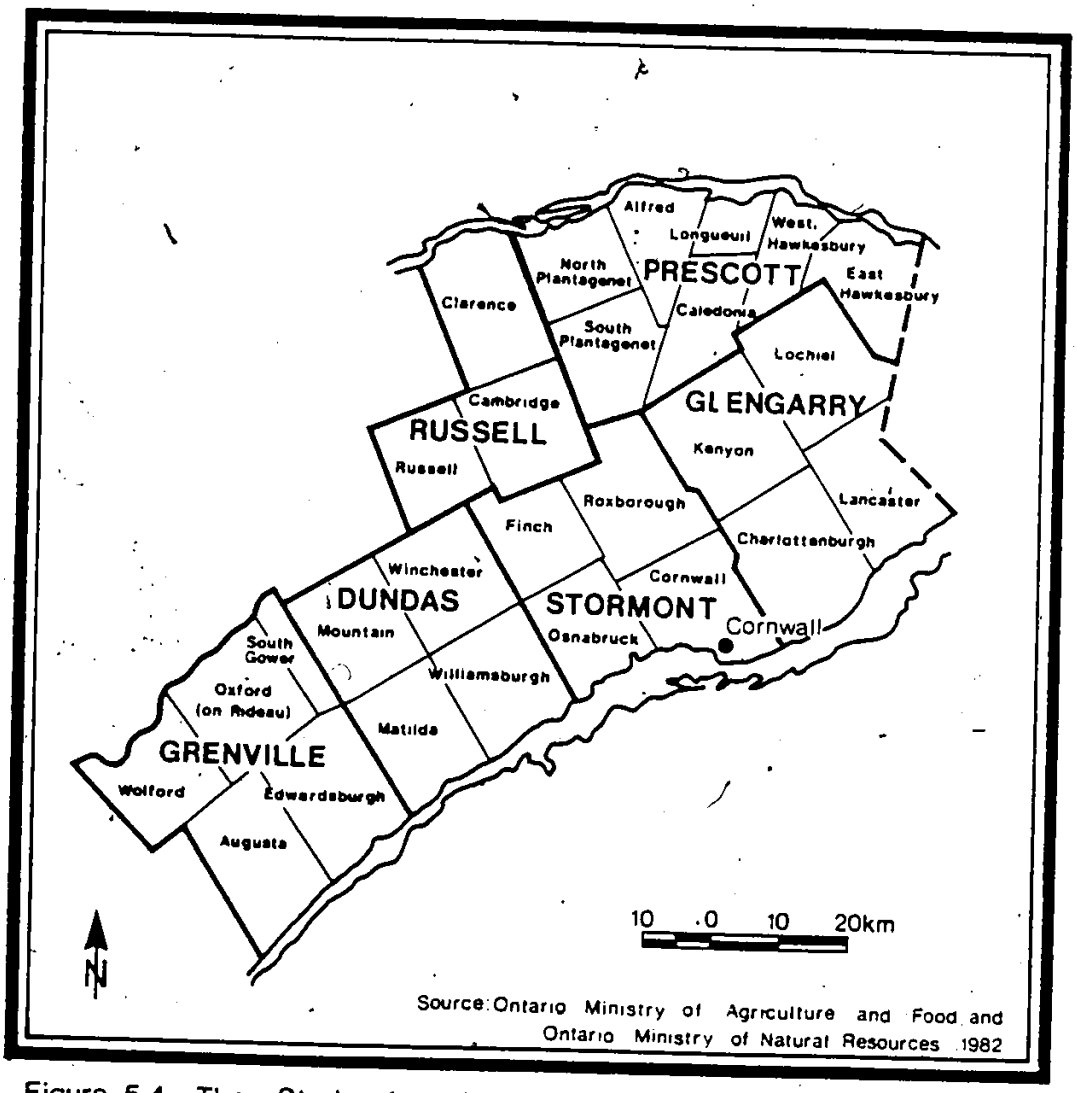


Figure 5.4 The Study Area in Detail

The goal programming model is depicted in detail in the following sections. Goals and constraints of the model are specified under the following headings: Technical/resource constraints; Economic efficiency in biomass production; Economic efficiency in energy conversion; Regional income generation; Energy efficiency; and Environmental quality. In each section mathematical statements of the goals and constraints are presented, along with the pertinent data bases. Each variable in the model is defined only at the point at which it is introduced in the text. To assist the reader, a full list of variable definitions is presented in Appendix F.

5.3.1 Technical/Resource Constraints

The first constraint specifies that the total area of land devoted to hybrid poplar production cannot exceed that available:

$$\sum_i a_{ij} \leq A_i \qquad 5.1$$

where a_{ij} is the amount of land in township i devoted to hybrid poplar plantations under management system j, and

A_i is the total amount of land available in township i.

As noted previously, the region has been defined as the six eastern-most counties of Ontario. Townships within the counties constitute production zones and land is allocated to biomass production at this spatial scale. Two of the three alternative poplar plantation management systems (j's) produce biomass that is suited to energy conversion processes. These are the 35K and 4K systems. To reiterate, the 35K system is characterized by plant spacings of approximately 1.0m x 1.0m, a planting density of 35,000 plants per hectare, and a rotation length of 2 years. Under the 4K system, plants are spaced 1.5m x 1.5m, at a density of 4,000 plants per hectare, and the rotation length is 5 years.

The six counties selected are the same as those for which land use was surveyed under the Forestry Agricultural Resource Inventory in Eastern Ontario (FARINEO). FARINEO is part of the New Forests in Eastern Ontario program, which has been referred to earlier in this chapter. The purpose of the FARINEO study was to "provide resource data upon which recommendations would be based for the optimization of agricultural and forestry production in Ontario" (OMAF and OMNR, 1982). Towards this, an inventory of present land use was conducted.

Land previously used for agriculture, but subsequently abandoned, is expected to constitute the major land resource base for hybrid poplar production. Two

categories of land use from the FARINEO study are appropriate:

Idle 1. Agricultural land idle for 1-10 years and in a state of reversion to natural vegetation; and

Idle 2. Agricultural land idle for more than 10 years and supporting native vegetation.

The combined area of land categorized as Idle 1 or Idle 2 is reported, by township, in Table 5.1. These areas constitute the right-hand-sides of the land availability constraints (the A_i's).

The entire quantity of biomass produced in the region annually must be allocated to end uses. This condition is accommodated in the model via the following constraint:

$$\sum_i \sum_j \left[\frac{y_{ij} \, a_{ij}}{o_j} \right] - \sum_h [q_h] = 0, \qquad 5.2$$

where y_{ij} is the yield of poplar biomass in region i and grown under management system j,

o_j is the rotation length for management system j, and

q_h is the total amount of biomass, measured in oven dried tonnes (ODt's), allocated to conversion facility h.

The first expression on the left hand side of this

TABLE 5.1.

LAND AVAILABLE FOR BIOMASS PLANTATIONS IN EASTERN ONTARIO

Township	Area (ha.)
Dundas Co.	
Matilda	3,855
Mountain	2,039
Williamsburgh	3,928
Winchester	768
Glengary Co.	
Charlottenburgh	1,421
Kenyon	1,342
Lancaster	1,273
Lochiel	896
Grenville Co.	
Augusta	7,419
Edwardsburgh	4,100
S. Gower	1,410
Oxford	4,677
Wolford	3,191
Prescott Co.	
Alfred	584
Caledonia	711
E. Hawkesbury	1,239
W. Hawkesbury	1,304
Longueuil	325
N. Plantagenet	1,315
S. Plantagenet	1,089
Russell Co.	
Cambridge	1,571
Clarence	1,784
Russell	1,567
Stormont Co.	
Cornwall	5,570
Finch	1,391
Osnabruck	4,057
Roxborough	2,568
Total	61,293

Source: OMAF and OMNR, 1982.

equation represents total potential biomass production from the region, measured in ODt. The second expression accounts for the allocation of biomass, also measured in ODt, to conversion facilities. This constraint is pivotal in the model, since it helps to establish the structure which permits additivity of biomass production functions, specified in units per hectare, and biomass conversion functions, which are specified in units per ODt processed. The significance of this becomes more evident in the sections on income and employment generation.

Poplar yields vary with local physical site conditions, including soil and climate, and yields for individual clones have been found to differ markedly over areas as small as one hectare (Anderson and Zsuffa, 1983b). Ideally, the model would incorporate variations in yield that result from differences in site conditions. Although a framework for classifying sites according to suitability for poplar production has been developed (Barkley et al., 1983), extensive field mapping has not been undertaken. Moreover, existing yield data do not reflect the full range of sites that may be encountered. Ministry of Natural Resources scientists believe, however, that with increased field experience it will be possible to match individual clones to local sites in order to achieve consistently high yields (Anderson and Zsuffa, 1983a). On the basis of this, the assumption is made that yields are everywhere the same

and that these yields are the maximum achievable under each management system. Accordingly, the assumed yields are 16 oven dried tonnes per hectare per annum (ODt/ha./a.) for the 35K system and 8.35 ODt/ha./a. for the 4K system (Evers et al., 1983). In the event that better information was available on variations in yield as a function of specific site characteristics, it would be a relatively easy matter to account for such variations within the model, assuming the spatial distribution of the appropriate site characteristic(s) was also known.

For these yields and with rotation lengths of 2 and 5 years for the 35K and 4K systems, respectively, annual potential biomass productivity values for each township, under each management system, have been estimated and are reported in Table 5.2. The higher per unit area productivity of the 35K system and the shorter rotation length lead to markedly higher estimates of potential biomass productivity for this management alternative.

Constraints may also be imposed to define the sizes of conversion facilities for each end use. Upper limits on the sizes of conversion facilities, for example, might reflect anticipated maximum demand for energy. Available technology might impose upper and lower limits on conversion facility size. Upper and lower limits might also define the size range over which a conversion facility can be built to provide positive economic returns. In some

TABLE 5.2

ESTIMATED POTENTIAL BIOMASS PRODUCTION IN EASTERN ONTARIO UNDER ALTERNATIVE PLANTATION MANAGEMENT SYSTEMS

Township	Annual Production (ODt) 35K	4K
Dundas Co.		
Matilda	30,840	6,438
Mountain	16,312	3,405
Williamsburgh	30,624	6,393
Winchester	6,144	1,283
Glengary Co.		
Charlottenburgh	11,368	2,373
Kenyon	10,736	2,241
Lancaster	10,184	2,126
Lochiel	7,168	1,496
Grenville Co.		
Augusta	59,344	12,388
Edwardsburgh	32,800	6,847
S. Gdwer	11,280	2,355
Oxford	37,416	7,811
Wolford	25,528	5,329
Prescott Co.		
Alfred	4,672	975
Caledonia	5,688	1,187
E. Hawkesbury	9,912	2,069
W. Hawkesbury	10,432	2,178
Longueuil	2,600	543
N. Plantagenet	10,520	2,196
S. Plantagenet	8,712	1,819
Russell Co.		
Cambridge	12,568	2,624
Clarence	14,272	2,979
Russell	12,536	2,617
Stormont Co.		
Cornwall	44,560	9,302
Finch	11,128	2,323
Oshabruck	32,456	6,775
Roxborough	20,544	4,289
Total	490,344	102,361

circumstances, there may be only one feasible size for a particular conversion facility. This would be the case when the facility is built to provide energy to a specific and fixed demand source, such as an institution or an industrial complex.

For this model, size constraints are expressed in terms of the quantity of biomass processed annually, which can be directly related to more conventional measures of size, such as annual output. The upper limit is expressed algebraically as:

$$q_h \leq Q_h^U, \qquad 5.3$$

where Q_h^U is an upper limit on the size of conversion facility h.

Constraints which specify a minimum size for a conversion facility are expressed as:

$$q_h \begin{cases} \geq Q_h^L \\ 0 \text{ otherwise,} \end{cases} \qquad 5.4$$

where Q_h^L is a lower limit on the size of conversion facility h.

When a conversion facility is to be restricted to one specified size, the constraint is of the following form:

$$q_h \begin{cases} = Q_h^* \\ 0 \text{ otherwise,} \end{cases} \qquad 5.5$$

where Q_h^* is a specified size for conversion facility h.

Situations in which constraints of the form , represented by equations 5.4 and 5.5 are binding on model solutions may require that the model be solved iteratively.

For this study, the size of the co-generation facility is restricted to a maximum of 50MW (approximately 675,000 ODt input per annum). This is the upper limit imposed by existing technology on wood-fired electricity plants of the design considered in this study (Sekington, 1982). Plants capable of outputting only a few hundred kilowatt hours are also feasible and, initially, no lower limit on the size of the co-generation facility is specified.

If biomass is assigned to methanol production, the quantity must be sufficient to supply a plant capable of outputting at least 300 tonnes per day (tpd) of fuel alcohol. This is the minimum sized plant for which the available cost information is believed to be reliable. There are also indications from the literature that plants of a smaller size would experience substantial diseconomies of scale (Office of Technology Assessment, 1980; Peat, Marwick and Partners, 1981b; Pfeiffer, 1978). Annual

biomass input to a 300 tpd methanol plant of the design considered here is equivalent to 37,620 ODt (0.38 ODt/tonne of methanol). No upper size limit is specified for the methanol plant, since even facilities of medium capacity (3,000 tpd) would consume almost all of the biomass that could be produced within the region.

Annual biomass feedstock requirements for the institutional heating complex considered here are fixed at 2,365 ODt/year.

5.3.2 Economic Efficiency in Biomass Production

Operators of enduse facilities may choose to purchase or lease land and establish their own poplar plantations. In Eastern Ontario, for example, hybrid poplar plantations have been established by Domtar Ltd. to provide their own material source for the production of pulp and paper. Similarly, Grenville Christian College has established poplar plantations in anticipation of utilizing the biomass as a heating fuel. Under these circumstances, break-even returns or even negative returns to biomass production may be acceptable, as long as total costs (biomass production and conversion) are lower than if the cheapest alternative feedstock were used.

Alternatively, individual landowners could establish poplar plantations and sell the biomass directly to end-use

facilities. In this case, land owners would expect positive net economic returns to the investment of their resources. Moreover, the returns to resources invested in biomass plantations should at least equal the returns from alternative uses. These are assumed to be the circumstances under which the majority of poplar plantations will be established in Eastern Ontario.

To incorporate economic efficiency in biomass production as a goal in the programming model requires information on the returns to biomass production under each of the alternative management systems. Field tests have revealed that poplars will regenerate successfully as many as four times after harvesting, thus giving up to five harvests from each planting. After the fifth harvest, it will generally be necessary to re-cultivate and replant the sites. These operations involve costs that are substantial in relation to maintenance costs incurred over the five rotations, and are also essentially fixed costs. Five rotations, therefore, represent a standard investment period for a hybrid poplar plantation and will henceforth be referred to as a plantation cycle. The length of a plantation cycle will, of course, vary with management systems, since rotation lengths differ.

A measure of economic efficiency can be obtained by estimating the net present value of the land (discounted revenues minus discounted costs), on the basis of the per

unit area costs and revenues incurred over the duration of the plantation cycle. Because the lengths of the plantation cycles differ for the two management systems, total net present value of the land must be converted to an annual average in order to permit comparisons.

Utilizing a net present value formulation, the economic efficiency goal is expressed algebraically as:

$$\sum_i \sum_j [(\sum_{t=0}^{I_j} \frac{R_{ijt} - C_{ijt}}{(1 + r)^t}) I_j^{-1}] a_{ij} \bullet d_1^- - d_1^+ = V^p \qquad 5.6$$

Objective Function: Min. d_1^-.

where R_{ijt} are the per hectare returns to hybrid poplar production in area i, under management system j, in year t,

C_{ijt} are the per hectare costs for hybrid poplar production in area i, under management system j, in year t,

r is the rate of discount,

t is time, in years,

I_j is the length, in years, of the plantation cycle for management system j, and

V^p is a target for the annual level of return to hybrid poplar production in the region.

For this goal, the primary concern is to minimize the negative deviation from the specified target level.

Positive deviations from the target are, however, acceptable. Only the negative deviation is therefore entered into the objective function, as indicated above.

The goal is formulated such that for each township the model will allocate land to biomass production under the management system that provides the highest net returns. This will promote goal achievement. Allocation of land units to the management system with the lower coefficient, or the allocation of land units to production for which the returns to plantations are negative may cause retrogression from the target.

When competition for resouces is anticipated, net returns from biomass production should be compared to those from alternative uses. In this case, only land currently idle is considered to be available and resource competition is not expected. In this context, therefore, it is assumed that the best use from an economic standpoint will be the plantation management system with the highest net return.

Schedules of plantation management activities over the production cycles for each of the two management systems and examples of the associated costs and revenues are presented in Appendix A. A summary of the costs is presented in Table 5.3.

For each management system, all costs are assumed to be the same for each township, except for the costs of transporting biomass to Cornwall. Estimation of transport

TABLE 5.3

SUMMARY OF BIOMASS PRODUCTION COSTS FOR ALTERNATIVE PLANTATION MANAGEMENT SYSTEMS

Operation	System 35K		System 4K	
	Year	Cost ($/ha.)	Year	Cost ($/ha.)
Site preparation	0	458.75	0	458.75
Planting	0	1,610.50	0	337.50
Weed control	4	212.50	2	275.00
Fertilizing	every 2	92.50	-	-
Harvesting	every 2	328.00	every 5	643.34

Source: Ontario Ministry of Natural Resources, 1981.

costs involved calculating the average distance to Cornwall of a set of points within each township. The points were located according to a stratified random sampling of the region. Applying the transportation cost factor of 20.7 cents/tonne-kilometer to these estimated average distances resulted in the per unit transportation costs reported in Appendix B.

Revenues are simply a function of the quantity of biomass produced and the price paid per tonne of biomass delivered to the processing facility. Expectations are that prices paid will be between $35.00 and $50.00 per oven dried tonne equivalent.

Tables 5.4 and 5.5 present, for the 35K and 4K systems respectively, estimates of the average annual net present value of land under biomass production in each township, at alternative biomass supply prices. Comparison of the tables reveals that the 35K system yields higher economic returns for producing areas closer to the processing facilities, while the 4K system provides higher returns for townships at greater distances.

Inspection of the tables also reveals that economic returns to both management systems are sensitive to biomass supply price. The 35K system is considerably more sensitive, however, with an estimated slope of 9.8 versus 3.8 for the 4K system. Both management systems are less sensitive to distance, and once again the 35K system

TABLE 5.4

ANNUAL NET PRESENT VALUE OF LAND DEVOTED TO BIOMASS PRODUCTION UNDER THE 35K MANAGEMENT SYSTEM

Township	Annual Net Present Value ($/ha./a.)				
	Biomass Supply Price ($/ODt)				
	50.00	45.00	42.50	40.00	35.00
Dundas Co.					
Matilda	68.49	19.45	-5.07	-29.59	-78.62
Mountain	55.29	6.25	-18.27	-42.78	-91.82
Williamsburgh	97.32	48.28	23.76	-0.76	-49.79
Winchester	77.83	28.79	4.27	-20.25	-69.29
Glengary Co.					
Charlottenburgh	137.32	88.28	63.76	39.24	-9.80
Kenyon	106.66	57.62	33.10	8.58	-40.46
Lancaster	110.11	61.07	36.55	12.03	-37.00
Lochiel	86.15	37.11	12.60	-11.92	-60.96
Grenville Co.					
Augusta	8.80	-40.24	-64.76	-89.28	-138.32
Edwardsburgh	38.55	-10.19	-34.71	-59.23	-108.27
S. Gower	33.57	-15.47	-39.99	-64.51	-113.55
Oxford	18.14	-30.90	-55.42	-79.94	-128.98
Wolford	-11.91	-60.95	-85.47	-109.99	-159.02
Prescott Co.					
Alfred	47.37	-1.66	-26.18	-50.70	-99.74
Caledonia	72.35	23.31	-1.21	-25.73	-74.77
E. Hawkesbury	58.13	9.10	-15.42	-39.94	-88.98
W. Hawkesbury	52.25	3.21	-21.31	-45.83	-94.87
Longueuil	46.16	-2.88	-27.40	-51.92	-100.96
N. Plantagenet	48.19	-0.85	-25.37	-49.89	-98.93
S. Plantagenet	75.39	26.35	1.84	-22.68	-71.72
Russell Co.					
Cambridge	77.83	28.79	4.27	-20.25	-69.29
Clarence	44.53	-4.51	-29.03	-53.54	-102.58
Russell	62.40	13.36	-11.16	-35.68	-84.72
Stormont Co.					
Cornwall	148.48	99.45	74.93	50.41	1.37
Finch	97.73	48.69	24.17	-0.35	-49.39
Osnabruck	123.92	74.88	50.36	25.84	-23.20
Roxborough	113.97	64.93	40.41	15.89	33.15

TABLE 5.5

ANNUAL NET PRESENT VALUE OF LAND DEVOTED TO BIOMASS PRODUCTION UNDER THE 4K MANAGEMENT SYSTEM

Township	Annual Net Present Value ($/ha./a.)				
	Biomass Supply Price ($/ODt)				
	50.00	45.00	42.50	40.00	35.00
Dundas Co.					
Matilda	50.94	31.91	22.39	12.87	-6.16
Mountain	45.82	26.78	17.27	7.75	-11.29
Williamsburgh	62.14	43.10	33.58	24.06	5.03
Winchester	54.57	35.53	26.02	16.50	-2.54
Glengary Co.					
Charlottenburgh	77.66	58.63	49.11	39.59	20.55
Kenyon	65.76	46.72	37.21	27.69	8.65
Lancaster	67.10	48.06	38.55	29.03	9.99
Lochiel	57.80	38.76	29.25	19.73	0.69
Grenville Co.					
Augusta	27.77	8.74	-0.78	-10.30	-29.33
Edwardsburgh	39.44	20.40	10.88	1.37	-17.67
S. Gower	37.39	18.35	8.83	-0.68	-19.72
Oxford	31.40	12.36	2.84	-6.67	-25.71
Wolford	19.73	0.70	-8.82	-18.34	-37.37
Prescott Co.					
Alfred	42.75	23.71	14.19	4.68	-14.36
Caledonia	52.44	33.41	23.89	14.37	-4.67
E. Hawkesbury	46.92	27.89	18.37	8.85	-10.18
W. Hawkesbury	44.64	25.60	16.08	6.57	-12.47
Longueuil	42.27	23.24	13.72	4.20	-14.83
N. Plantagenet	43.06	24.03	14.51	4.99	-14.05
S. Plantagenet	53.82	34.59	25.07	15.55	-3.49
Russell Co.					
Cambridge	54.57	35.53	26.02	16.50	-2.54
Clarence	41.64	22.61	13.09	3.57	-15.46
Russell	48.58	29.54	20.03	10.51	-8.53
Stormont Co.					
Cornwall	82.09	62.96	53.44	43.92	24.89
Finch	62.29	43.26	33.74	24.22	5.18
Osnabruck	72.46	53.42	43.91	34.39	15.35
Roxborough	68.60	49.56	40.04	30.53	11.49

exhibits greater sensitivity (slope of -2.03 versus -0.79 for the 4K system). The expected sensitivity of net present value calculations to the rate of discount is borne out by the results illustrated in Figure 5.5

For the base scenario in this study, a biomass supply price of $42.50/ODt is assumed. At this price, the FARINEO region closely approximates the maximum economic supply area for biomass produced in Eastern Ontario and delivered to a facility in Cornwall. There are only an additional three townships in the vicinity (North Gower, Osgoode and Gloucester) in which biomass could be produced and yield positive financial returns (under the 4K system), but which are outside the FARINEO region and hence excluded from this study.

5.3.3 Economic Efficiency in Energy Conversion

A primary concern in establishing facilities for the conversion of biomass is that energy can be produced at a price that is competitive with alternative energy sources. This concern is embodied in a goal that expresses the desire to achieve a specified level of financial return to energy conversion processes in the region. Mathematically:

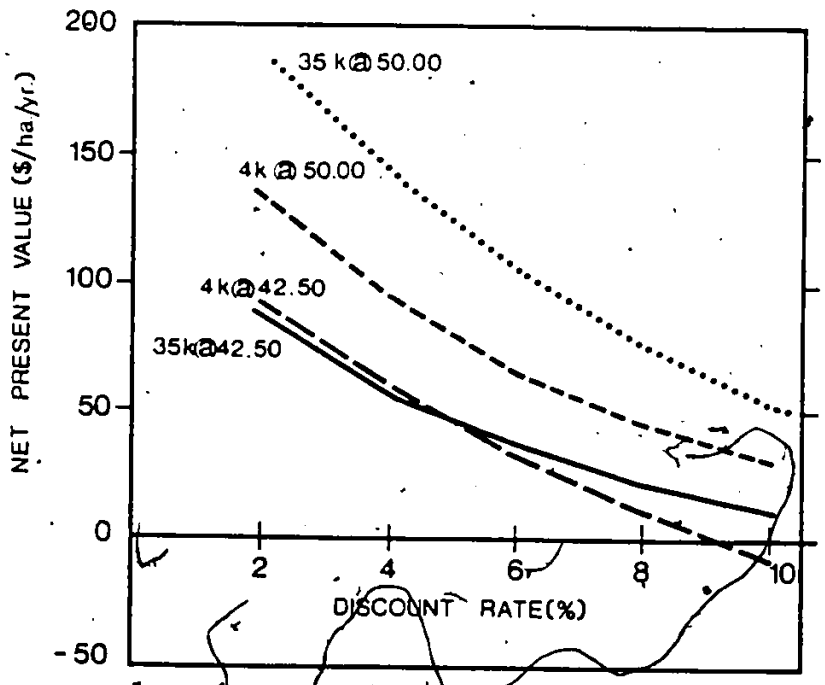


Figure 5.5 Sensitivity of Annual Net Present Value Calculations to the Rate of Discount: The Example of Kenyon Township, Glengary Co.

$$\sum_h (R_h - C_h)\ q_h + d_2^- - d_2^+ = V^c \qquad 5.7$$

Objective Function: Min. d_2^-,

where R_h are the annual returns per oven dried tonne of wood input for biomass conversion facility h,

C_h are the annual costs per oven dried tonne of wood input for biomass conversion facility h, and

V^c is a target level for annual returns to energy conversion in the region.

As in the case of the previous goal, the concern is to minimize negative deviations from the target level. Positive deviations are permitted, though, and only the negative deviation is therefore entered into the objective function.

Development of end-use facilities for which the economic return per unit of biomass input is low, or negative, will cause retrogression from the target. On the other hand, development of energy end uses for which there is a high rate of return, relative to other energy conversion processes, will promote goal achievement.

In Canada, examples of wood-fired electricity plants or methanol plants that use wood as a feedstock do not exist. Similarly, in the United States there are no fuel

alcohol plants utilizing wood as a feedstock. The city of Burlington, Vermont, however, is supplied with electricity from a 50MW wood-fired electrical generating plant, commissioned in 1984. Practical experience with wood-based energy systems, other than commercial and domestic heating, though, is extremely limited.

Numerous studies have been commissioned, however, to assess the economic feasibility of biomass energy conversion facilities. For electricity generation, notable examples of such studies in North America include Acres Shawnigan Ltd (1979), Bliss and Blake (1977), Evans (1974), Peat, Marwick and Partners (1981b) and Wayman (1977). There has been less interest in methanol plants, but economic feasibility studies of note include Bliss and Blake (1977), Intergroup Consulting Economists Ltd (1978), McKay and Sutherland (1978) and Peat, Marwick and Partners (1981b). Differing assumptions with respect to plant design, input costs and financing arrangements have led to widely different cost assessments and inconsistent conclusions regarding the feasibility of biomass conversion facilities.

Several institutions and small commercial operations throughout the northeastern U.S. and Canada have installed wood-fired heating plants. The most extensive economic feasibility studies undertaken in Canada are those by Dick Consulting Ltd (1981a, 1981b).

The data for electricity and steam co-generation is

from Peat, Marwick and Partners (1981b). The relatively recent origin of this study, which ensures that the design is based on current technology, and the specific concern with development in Eastern Ontario makes it an appropriate source of information.

The engineering and cost analyses performed by Peat, Marwick and Partners (1981b) relate to a co-generation facility capable of producing 9MW of electricity (peak demand) and a maximum of 170,000 lb./hour of steam (140,000 lb./hour average) at 150 psi. Detailed cost and revenue information for this plant is reported in Appendix C, Table 1.

Amendments were made to the cost estimates presented by Peat, Marwick and Partners. These include the deflating of costs from 1981 to 1980 dollars, to ensure consistency of cost estimates in the model. Also, the heating value of wood chips is assumed to be 8,600 BTUs/lb. (20 GJ/tonne) in this study, whereas Peat, Marwick and Partners assumed a lower heating value of 8,500 BTUs/lb. The effect of this is to reduce the estimated consumption of wood and thereby the costs of feedstock.

The current study also assumes that it is possible to air dry the wood fuel from 50 percent moisture content, when green, to 30 percent moisture content. The reduction in moisture content will lead to improved boiler efficiency, with a consequent reduction in fuel use. Based

on results reported in Ash et al. (1980), boiler efficiency at 30 percent moisture content will be approximately 74 percent. The efficiency factor for wood burnt green is 65 percent, which is the value used by Peat, Marwick and Partners. At the lower moisture content and assuming the higher heating value, wood fuel consumption for the 9MW plant is estimated to be approximately 15.2 ODt/hour or 121,496 ODt/annum. The corresponding value estimated by Peat, Marwick and Partners (1981b) is 143,640 ODt/annum.

Returns to energy conversion are taken as the difference between the costs of producing energy from biomass and the cost of a substitute energy source. There are two energy products from the co-generation facility, steam and electricity, and the per unit costs of producing these are listed in Appendix C, Table 1. The cost of electricity to industrial users in Eastern Ontario is listed at 3.11 cents/KWH (Peat, Marwick and Partners, 1981b), while Fry (1984) suggested a price of $5.00 per million BTUs of process steam.

Assuming that the energy products (steam and electricity) are made available at these same prices, net returns to the conversion facility are approximately $400,000 per annum (see Appendix C). This is equivalent to a return of $3.41/ODt of biomass processed.

Returns to the co-generation facility are directly related to the quantity of biomass input. As noted above,

feedstock requirements are influenced by the moisture content of the wood when burnt. Burning the wood at 50 percent moisture content would demand an input of approximately 140,000 ODt/year, and this would result in negative economic returns, assuming an input cost of $42.50/ODt (Table 5.6). Drying the wood to less than 30 percent moisture content leads to improved economic returns, although this may require specialized equipment, the cost of which cannot be accounted for.

Estimates of economic efficiency are also sensitive to the assumed cost of the biomass feedstock. Maintaining the assumption that the wood is burnt at 30 percent moisture content, the effect of alternative biomass prices on returns per unit of input is illustrated in Table 5.7. The break-even price is approximately $46.00/ODt.

Although it is generally believed that there will be increasing returns to scale, consistent cost and input information does not exist for plants of different sizes. Constant returns to scale must therefore be assumed.

Peat, Marwick and Partners (1981b) have also conducted an economic and engineering feasibility study for a methanol plant. Their study, though, was concerned with a 60 tonnes per day (tpd) fuel alcohol output demonstration facility, which is considerably smaller than the anticipated size of a commercial installation (probably at least 300 tpd). Under any circumstances, the facility

TABLE 5.6

SENSITIVITY OF ECONOMIC EFFICIENCY CALCULATIONS FOR A 9MW CO-GENERATION FACILITY TO BIOMASS INPUT REQUIREMENTS

Biomass Input (ODt)	Net Annual Returns ($)	($/ODt)
115,000	690,716	6.01
120,000	478,216	3.99
125,000	265,716	2.13
130,000	53,216	0.41
135,000	-159,284	-1.18
140,000	-371,784	-2.66

TABLE 5.7

SENSITIVITY OF ECONOMIC EFFICIENCY CALCULATIONS FOR A 9MW CO-GENERATION FACILITY TO BIOMASS PRICES

Biomass Price ($/ODt)	Net Annual Returns ($)	Returns ($/ODt)
35.00	1,325,856	10.91
40.00	718,376	5.91
42.50	414,636	3.41
45.00	110,896	0.91
50.00	-496,584	-4.09

considered by Peat, Marwick and Partners would probably be economically inefficient. Research on the design and economic considerations relating to commercial scale wood-fed methanol plants in Canada was, however, undertaken by Intergroup Consulting Economists Ltd. (1978a).

Intergroup considered several alternative input options for a methanol facility. These included a wood-hydrogen input mix, wood only, and a wood-methane input combination. The highest methanol production costs were estimated for the wood only input option. Production costs are lowest for a wood-hydrogen fed facility, but this would have to be constructed adjacent to an electrolysis plant, from which the hydrogen would be obtained. The costs of producing methanol in a plant utilizing a wood-methane input mix are slightly higher than the wood-hydrogen alternative. The methane, though, could be obtained from either a municipal solid waste conversion plant or from natural gas. Given the potentially greater availability of methane versus hydrogen, a conversion facility utilizing a wood-methane feedstock is assumed.

A detailed listing of the costs associated with the construction and operation of a 1,000 tpd methanol plant is presented in Appendix C, Table 2. Several adjustments were made to the cost information listed by Intergroup. First, since their estimates were expressed in 1977 dollars, all costs were inflated to 1980 equivalents. Also, the method

of amortizing capital costs was changed to achieve consistency with capital financing assumptions employed by Peat, Marwick and Partners (1981b) with respect to the co-generation facility. This led to a slight increase in capital-related expenses. Finally, the assumed wood cost of $30.00/ODt was raised to $42.50/ODt. Under these assumptions, the cost of producing methanol is estimated at $208.69/tonne of fuel alcohol. This is equivalent to 16.5 cents per litre.

For this study, it is assumed that methanol would be produced as a substitute for imported oil. Net returns, therefore, are calculated as the difference between the cost of imported oil, at the plant gate, and the cost of producing methanol. With a calculated energy value of 17.87 MJ/litre of methanol, the cost of producing the fuel alcohol is equal to $9.23/GJ (see Appendix C). In September 1980, imported crude oil cost $38.85/barrel (Energy, Mines and Resources, 1980), or approximately 24.4 cents per litre. The energy content of crude oil is almost double that of methanol, at 34.62 MJ/litre. This translates into a cost of approximately $7.05/GJ. Added to the price of the imported crude oil are refining costs, estimated at $1.31/GJ (Ontario Ministry of Energy, 1981), for a total plant gate cost of $8.36/GJ (see Appendix C). Although methanol burns more efficiently than gasoline (Kliman, 1984), this would have a negligible effect on the per unit

prices estimated here.

A comparison of the unit costs reveals that imported crude oil is less expensive than methanol produced domestically using wood as a feedstock. Methanol would be even less competitive in relation to domestically produced oil.

For comparison, methanol is assumed to be sold at the same price as imported oil at the plant gate. The rationale for this derives from the belief that methanol should be viewed as a substitute for imported fuels, not those domestically produced. The net loss is equal to $0.87/GJ, or 1.56 cents/litre. Expressing this in terms of biomass input, $51.85 is lost for every tonne of wood converted to methanol (Appendix C).

Lower biomass prices inevitably lead to improved economic returns for a conversion facility. The estimated returns, however, are not particularly sensitive to biomass prices (Table 5.8). Even at $30.00/ODt, a substantial negative net financial return is calculated.

As in the case of the co-generation facility, information on the costs associated with methanol facilities of different sizes is not available, although positive returns to scale are expected. A report recently prepared for the Ontario Ministry of Energy (Ontario Energy Corporation, 1984) suggests, however, that methanol produced from wood is unlikely to be cost competitive with

TABLE 5.8

SENSITIVITY OF ECONOMIC EFFICIENCY CALCULATIONS FOR A 1,000 tpd METHANOL PLANT TO BIOMASS PRICES

Biomass Price ($/ODt)	Net Annual Returns ($)	($/ODt)
35.00	-5,593,758	-44.70
40.00	-6,190,676	-49.47
42.50	-6,488,509	-51.85
45.00	-6,787,594	-54.24
50.00	-7,384,511	-59.01

gasoline produced from oil in the near future. Declining oil prices through late 1984 and 1985 add support to this conclusion. Thus, although the necessary assumption of constant returns to scale may result in over-estimation of financial losses for larger plants, this is not considered to be a significantly limiting assumption.

In Ontario, the most extensive studies of the feasibility of wood-fired institutional heating complexes have been conducted by Dick Consulting Ltd. (1981a, 1981b) One investigation assessed the viability of converting four separate institutions, two in Northern Ontario and two in Eastern Ontario, to biomass-fed heating systems (Dick Consulting, 1981a). Conversion of the facilities in Northern Ontario was found not to be economically feasible nor particularly desirable from an employment generation perspective. For the two facilities in Eastern Ontario, the Rideau Regional Centre and Kemptville Agricultural College, the substitution of biomass for heating was considered to be economically feasible.

For this study, the information presented by Dick Consulting Ltd. (1981a) pertaining to the development of a wood-fired heating system for Kemptville Agricultural College is adopted as the data base for the institutional heating end-use alternative. This facility was chosen over the Rideau Regional Centre, since the latter is a much larger institution and perhaps less characteristic of the

greater number of institutions that might be candidates for fuel substitution.

Although the institutional heating alternative will typically involve the conversion of existing facilities, Dick Consulting assumed the installation of an entirely new heating complex, maintaining the existing equipment as a back-up. An estimate of the annual costs associated with a wood-fired heating system for an institution like Kemptville College is presented in Appendix C, Table 3. Note that the method of amortizing the capital cost is the same as that utilized for the co-generation facility and the methanol plant, to ensure consistency. The wood fuel costs are higher than those presented by Dick Consulting (1981a) because of the higher supply price assumed here. Maintenance costs are taken directly from Dick Consulting Ltd. (1981a). All costs have been deflated to 1980 dollar equivalents.

An appropriate measure of economic viability is whether installation of a wood-fired system would be cheaper than maintaining the existing system, which in the case of Kemptville College is oil-fired. The costs associated with maintaining the conventional system are also listed in Appendix C, Table 3.

The estimated annual savings achieved through conversion to a wood-fired heating system amount to over $24,000. This is equivalent to a financial benefit of

$10.25/ODt of wood feedstock. From an economic standpoint, therefore, conversion of institutions to wood-fired heating systems is the most attractive alternative, according to the criteria adopted here.

The assessment of economic viability is, of course, affected by the assumed biomass supply price. Even at $50.00/ODt, however, biomass substitution is preferable to maintaining the existing system, with an annual net saving of almost $6,500 or $2.75/ODt. At a biomass supply price of $35.00/ODt, the annual savings are approximately $42,000 or $17.75/ODt of biomass input.

5.3.4 Regional Employment Generation

Forest energy plantations may be one appropriate response to the depressed economic conditions of the Eastern region of Ontario. The merits of biomass energy developments as a regional development initiative will be evaluated in part with respect to employment generation. A report of the U.S. Office of Technology Assessment (1980), referred to previously in this regard, suggests that biomass energy developments are considerably more labour intensive than other energy resource developments. For Eastern Ontario, Peat, Marwick and Partners (1981a) and Wayman (1978) have predicted substantial employment generation through forest energy projects. Pertinent

questions in this study refer to the extent to which employment goals can be achieved with the available resources and which allocations of resources contribute most to employment. The appropriate goal can be expressed as:

$$\sum_i \sum_j [a_{ij} \; l^p_{ij}] + \sum_h [q_h \; l^c_h] + d_3^- - d_3^+ = L. \qquad 5.8$$

Objective Function: Min. d_3^-,

where l^p_{ij} is the number of worker-hours required per hectare for plantation operations under management system j,

l^c_h is the number of worker-hours required per oven dried tonne of biomass input to operate conversion facility h, and

L is a target for regional labour generation, expressed in worker-hours per year.

The negative deviation variable is entered into the objective function in order to minimize the extent to which employment falls below the target value. No concern exists for employment levels that exceed the target level, and the positive deviation variable is excluded from the objective function.

Labour inputs to biomass production are associated with site preparation, planting, harvesting operations,

biomass transportation, and routine plantation management operations, such as weed control and fertilizing. Since biomass plantations are assumed here to be established on existing operational farms, labour inputs of farm operators are not counted as new employment for the region. Hence, labour requirements associated with routine management practices, such as weed control and fertilizing, are not accounted for. Although operators would require additional labour for site preparation and planting, these inputs are expected to be minimal when spread over the plantation cycle. In the absence of reliable information, therefore, the omission of these inputs from the labour input accounting is not considered to be a major data limitation.

Harvesting of the biomass, though, is labour intensive relative to other plantation management activities. Estimates of the labour requirements associated with the harvesting of biomass from hybrid poplar plantations are presented in Peat, Marwick and Partners (1981a). To harvest the equivalent of 21,772.0Dt, they estimate a labour requirement of 7 persons at 1,500 hours per year, 10,500 hours in total. Expressed in terms of biomass harvested, this is equal to 0.48 worker-hours per ODt harvested. Thus, for the 4K system, with an assumed annual yield of 8.35 ODt/ha., the annual labour input required to harvest the plantation is equal to 4.01 worker-hours/ha./a.

The harvesting system described by Peat, Marwick and Partners (1981a) is typical of that used in forest operations and may be assumed to be characteristic of employment requirements for poplar plantations with rotations of greater than three years. With the smaller bole diameters of trees in rotations of less than three years, though, harvesting with a modified corn silage harvester has been possible (Pfeiffer, 1978). This harvesting system requires a smaller labour input per unit of harvested biomass. Based on information from Pfeiffer and that from Peat, Marwick and Partners (1981a), it is estimated that 5 persons for 1,500 hours would be required to harvest the equivalent of 21,772 ODt. This is equal to 0.34 worker-hours per ODt harvested, or for the 35K system, 5.44 worker-hours/ha./a.

The transportation of harvested biomass is also labour intensive. To deliver the equivalent of 399,165 ODt of biomass per annum from biomass plantations to a central facility, over an average distance of 35 kilometers, it has been estimated that 32 drivers would be required (Peat, Marwick and Partners, 1981a). Although the period over which drivers would be employed in a year is not stated in their report, the labour costs quoted indicate that they would be required only over the length of the harvesting season, that is, 1,500 hours. Total worker-hours for transportation of the listed quantity of biomass,

therefore, is estimated at 48,000. This is equivalent to 0.0034 driver-hours/ODt/km. By applying this factor to the assumed yields for the respective management systems and multiplying by the appropriate distance, per hectare labour coefficients for biomass transportation for each township and each management system were obtained. Added to these were the harvesting labour coefficients, to obtain total employment generation coefficients for biomass production (Table 5.9).

Estimates of labour demand for the conversion facilities are also available. These estimates do not include employment for the construction of the facilities, which is considered to be short term, but do include all personel involved in the routine operation of the various facilities. For the co-generation facility, an estimated 22 persons will be required annually to operate the plant and the woodyard (Peat, Marwick and Partners, 1981b). Assuming 8-hour shifts, total labour input is calculated at 57,376 hours for the 326 day annual operating period. Expressed in terms of the wood input requirements for the 9MW plant, this is equal to 0.47 hours/ODt/a. As in the case of conversion costs, labour inputs are assumed to be a linear function of plant size.

Intergroup (1978a) estimate the annual labour requirements for the 1,000 tpd methanol plant to be 44 persons. Over the 330 day annual operating period, and

TABLE 5.9

REGIONAL EMPLOYMENT GENERATION COEFFICIENTS FOR BIOMASS PRODUCTION UNDER ALTERNATIVE MANAGEMENT SYSTEMS

Township	Employment Generation Coefficent (worker-hours/ha.) 35K	4K
Dundas Co.		
Matilda	8.21	5.46
Mountain	8.57	5.64
Williamsburgh	7.44	5.05
Winchester	7.96	5.33
Glengary Co.		
Charlottenburgh	6.37	4.50
Kenyon	7.19	4.92
Lancaster	7.10	4.88
Lochiel	7.74	5.21
Grenville Co.		
Augusta	9.81	6.29
Edwardsburgh	9.01	5.87
S. Gower	9.15	5.95
Oxford	9.55	6.16
Wolford	10.37	6.58
Prescott Co.		
Alfred	8.78	5.75
Caledonia	8.11	5.40
E. Hawkesbury	8.49	5.60
W. Hawkesbury	8.65	5.69
Longueuil	8.81	5.77
N. Plantagenet	8.76	5.74
S. Plantagenet	8.03	5.36
Russell Co.		
Cambridge	7.96	5.33
Clarence	8.86	5.79
Russell	8.38	5.54
Stormont Co.		
Cornwall	6.07	4.34
Finch	7.43	5.05
Osnabruck	6.73	4.68
Roxborough	7.00	4.82

again assuming 8-hour shifts, this labour input is calculated at 116,160 hours. As a ratio of wood feedstocks, this is equal to 0.93 worker-hours/ODt. Again, labour inputs must be assumed to be linearly related to plant size.

Since the institutional heating alternative involves conversion of an existing facility, the concern here is not with total employment in the heating plant, but only with additional labour requirements necessitated by conversion to a wood-fired system. Current employment in the heating plant at Kemptville College is five. The only additional labour requirements would be for an operator of an overhead loader, for an annual 3 month period. This amounts to a total of 480 hours annually, the equivalent of 0.20 worker-hours/ODt of biomass input.

Note that the various labour input coefficients estimated here account only for direct labour requirements. Biomass energy developments might generate further employment via increased demands for goods and services. Indirect labour generation effects could be accounted for by applying appropriate regional employment multipliers to the estimated coefficients, but this has not been done for this study.

5.3.3 Regional Income Generation

Expenditures on goods and services also contribute to economic development, and the extent to which a project leads to increased expenditures is a measure of its ability to stimulate the regional economy. The expenditures made in relation to a development project within the region are referred to here as regional income generation. For this research, relevant questions refer to the contribution biomass energy developments may make in terms of regional income generation and the effects on this potential of alternative goal priority orderings and input assumptions. The form of the goal relating to regional income generation is similar to that for employment generation and is expressed as:

$$\sum_i \sum_j [a_{ij}\ m_{ij}^p] + \sum_h [q_h\ m_h^c] + d_4^- - d_4^+ = M. \qquad 5.9$$

Objective Function: Min. d_4^-,

where m_{ij}^p is the per hectare dollar expenditure on plantation operations under management system j,

m_h^c is the dollar expenditure per oven dried tonne of biomass required for the operation of conversion facility h, and

M is a target for regional income generation, expressed in dollars per year.

The appropriate variable to be entered into the objective function is the negative deviation variable, as indicated above.

When estimating regional income generation coefficients, only those expenditures made within the region are included. In most cases, capital items required in biomass production and energy conversion would be manufactured, and in some cases, even purchased, outside the region. The regional income generation effects of such expenditures would be negligible. Items within this category would include farm machinery, transportation equipment and capital equipment for the conversion plants. On the other hand, most expenditures on goods and services required for the routine operation of plantations and conversion facilities would contribute to regional income generation. Additionally, returns to plantation owners can reasonably be construed as regional income generation.

Under the category of biomass production, expenditures contributing to regional income generation are taken as those on labour for harvesting, operating costs of harvesting equipment and expenditures on labour for the transportation of biomass. As noted above, regional income is also generated via the returns to land under plantations. Peat, Marwick and Partners (1981a) have

estimated the costs associated with the labour required for biomass harvesting (see previous section). Total annual expenditure for the 7 workers is listed at $100,591. This is equivalent to $4.62/ODt harvested and, for the 4K system, means an expenditure of $38.58/ha./a. Lower labour requirements per unit of biomass harvested from the 35K system leads to a lower estimate of $72,722 for the total expenditure on labour for harvesting. This is equal to $3.34/ODt harvested and, because of the larger quantity harvested annually, a higher per hectare coefficient of $53.50/ha./a.

The operating costs of harvesting equipment are also estimated by Peat, Marwick and Partners (1981a). These expenditures are valued at $83,750. As a ratio of the almost 22,000 ODt harvested, this is equal to $3.85/ODt. For a 4K plantation system, the regional income generation coefficient for operating costs is $32.15/ha./a. As in the case of labour, equipment for harvesting the 35K plantations is less, and total operating expenditures are estimated at $68,245. The per unit biomass output coefficient is $3.13/ODt and the appropriate income generation coefficient is calculated to be $50.15/ha./a.

Total expenditures on labour for the transportation of biomass were estimated at $576,000 for the 32 drivers (Peat, Marwick and Partners, 1981a). This translates into $0.04/ODt/km. Expenditures on labour for transportation on

a township basis were obtained by multiplying this coefficient by the appropriate distance. The coefficients for each township were then multiplied by the respective yields for the 35K and 4K systems, to obtain coefficients expressed in dollars per hectare per annum.

Summing the coefficients for harvesting labour, equipment operating costs, expenditures on transportation labour and annual net returns to landowners (from Tables 5.4 and 5.5), total regional income generation coefficients for biomass production under the 35K and 4K systems, for each township, were calculated (Table 5.10). Regional income generation coefficients are typically higher for plantations under the 35K management system.

Contributions to regional income from the conversion facilities may arise from expenditures on labour, maintenance materials and other operating expenses. Net returns to the conversion facilities are not included. This is primarily because of difficulties associated with the methanol plant. Earlier calculations reveal that methanol could not be sold at a competitive price and still provide postive financial returns. If such a facility were built, however, the burden of financial losses may not fall upon the operators of the facility and/or the region. Federal or provincial governments may be prepared to subsidize the facility, recognizing its potential to contribute to energy self-sufficiency goals and regional economic development.

TABLE 5.10

REGIONAL INCOME GENERATION COEFFICIENTS FOR BIOMASS PRODUCTION UNDER ALTERNATIVE MANAGEMENT SYSTEMS

Township	Income Generation Coefficient ($/ha./a.)	
	35K	4K
Dundas Co.		
Matilda	131.22	110.15
Mountain	122.18	107.21
Williamsburgh	150.96	116.60
Winchester	137.62	112.25
Glengary Co.		
Charlottenburgh	178.35	125.55
Kenyon	157.46	118.69
Lancaster	159.72	119.47
Lochiel	143.32	114.41
Grenville Co.		
Augusta	90.35	96.80
Edwardsburgh	110.92	103.52
S. Gower	107.31	102.34
Oxford	96.74	98.89
Wolford	76.16	92.17
Prescott Co.		
Alfred	116.77	105.43
Caledonia	133.86	111.02
E. Hawkesbury	124.13	107.84
W. Hawkesbury	120.10	106.52
Longueuil	115.93	105.16
N. Plantagenet	117.32	105.61
S. Plantagenet	135.95	111.70
Russell Co.		
Cambridge	137.62	112.25
Clarence	114.81	104.80
Russell	127.05	108.80
Stormont Co.		
Cornwall	186.00	129.04
Finch	151.24	116.69
Osnabruck	169.18	122.56
Roxborough	162.36	120.32

Economic losses would then be effectively spread over the province or nation. Under such an arrangement, the net effects on the region in terms of income generation would be extremely difficult to identify.

Expenditures related to the operation of the conversion facilities which may contribute to regional income generation are listed in Table 5.11. For the co-generation facility, the total annual expenditure is estimated at $818,792, which is the equivalent of $6.74/ODt of biomass feedstock. Total expenditures for the methanol facility equal approximately $6.4 million, the equivalent of $51.40/ODt of feedstock. Expenditures associated with the institutional heating plant are estimated at $18,194, a per unit expenditure of $7.69/ODt. The per unit expenditures are considerably higher for the methanol facility and, as in the case of labour generation, this end-use alternative is expected to have the greatest potential to contribute to regional economic development.

As in the case of all previous production functions, these expenditures are assumed to be a linear function of plant size. The possibilities of non-linearities is acknowleged, however.

The regional income generation coefficients, like those for employment generation, capture only the direct effects. Regional economic multipliers could be applied to the coefficients in order to estimate the broader regional

TABLE 5.11

CONVERSION FACILITY EXPENDITURES CONTRIBUTING TO REGIONAL INCOME GENERATION

A. 9MW Co-Generation Plant

	$
Operating staff	415,356
Maintenance labour and materials	293,408
Administration and general	110,028
Total	818,792
Expenditures per unit of input	$6.74/ODt

B. 1,000 tpd Methanol Plant

	$
Power	195,822
Labour	872,685
Supervision and administration	349,074
Water	749,232
Maintenance	3,643,992
General overheads	621,522
Total	6,432,327
Expenditures per unit of input	$51.40/ODt

C. Institutional Heating

	$
Maintenance	13,574
Labour	4,400
Total	18,194
Expenditures per unit of input	$7.69/ODt

spending effects, but no attempt is made to do this here.

5.3.6 Energy Efficiency

Increasing recognition of the importance of energy as a resource has led to greater emphasis on evaluating the energy efficiency of development proposals, particularly those relating to energy supply. Energy inputs refer not only to direct requirements in the form of oil, electricity or gas, but also to the energy required to build and maintain capital equipment and the energy embodied in other inputs to the production process. These indirect energy inputs also represent costs in terms of energy resources and must be accounted for.

There are major differences in opinion with respect to how far one should go in including indirect energy inputs. Some believe that energy values should be ascribed to all natural resource inputs, labour, plant and equipment, and variable inputs. Others are more conservative and exclude items such as energy embodied in natural resources and labour. The energy accounting approach adopted here tends to be conservative.

Concerns for energy efficiency are expressed by the following goal constraint:

$$\sum_h [(e_h^{co} - e_h^{cn}) q_h] - \sum_i \sum_j [e_{ij}^{pn} a_{ij}] + d_5^- - d_5^+ = E. \qquad 5.10$$

Objective Function: Min. d_5^-,

where e_h^{co} is the gross energy output, per oven dried tonne of biomass input, from conversion facility h,

e_h^{cn} are the energy inputs to the conversion process, expressed in units per oven dried tonne of input, in conversion facility h,

e_{ij}^{pn} are the per hectare energy inputs to biomass plantations in township i, under management system j, and

E is a target level for total net energy production from the regional biomass energy system.

The main concern is to minimize the extent to which net energy output falls short of the target value. As in the cases of all previous goals, therefore, the negative deviation variable corresponding to this goal is entered into the objective function, while the positive deviation variable is excluded.

The goal constraint seeks to maximize net energy production from the total biomass energy system: that is, including both biomass production and energy conversion phases. Note that this goal constraint does not include the

net energy of the biomass as an input, but only the energy inputs required to produce the biomass (ie., e_{ij}^{pn}). Explanation of this is offered following the description of the various biomass production energy coefficients.

For biomass production, energy inputs include those for site preparation, planting, the manufacture and application of fertilizers and pesticides, harvesting and the transportation of biomass. The energy required for the clearing of existing vegetation from plantation sites is not accounted for, primarily because of the absence of information. While this may be an energy intensive operation, it is possible that the energy costs could be recouped by converting the biomass cleared to useable energy.

Other site preparation costs relate to the cultivation of the land. Information on energy used in site preparation for field crops in Ontario (Ouellette-Babin, 1982) was used to estimate the same energy costs for biomass plantations. A combined energy input of 1.97 GJ/ha. was estimated for plowing, discing and cultivating. Spreading these energy costs over the appropriate plantation cycle length, the energy input coefficients are 0.18 GJ/ha./a. for the 35K system and 0.08 GJ/ha./a. for the 4K system.

Mechanized planting systems are assumed to be used in the case of the 35K system. Assuming that energy for

planting will be similar to that consumed in agricultural systems, the energy input is 0.364 GJ/ha. (Ouellette-Babin, 1982). This amounts to 0.03 GJ/ha./a. when spread over the plantation cycle. Non-mechanized planting is assumed for the 4K system and thus there is no energy input to planting.

Ash et al. (1980) suggest that the indirect energy requirements associated with harvesting are approximately 27.7 percent of the energy consumed directly. This same indirect energy factor is used for site preparation and planting. Total energy required for site preparation and planting for the 35K system is therefore estimated to equal 0.27 GJ/ha./a. and 0.10 GJ/ha./a for the 4K system. A summary of these energy costs is presented in Table 5.12.

35K plantations require the application of 68.1 kg/ha. of fertilizer every two years (Ontario Ministry of Natural Resources, 1983). Based on information reported in Inman et al. (1977), the energy required to manufacture this quantity of fertilizer is 1.13 GJ. At four applications over the plantation cycle, total energy associated with the manufacture of fertilizer is 4.52 GJ/ha. To this is added the energy cost of fertilizer applications. The value used was obtained from Ouellette-Babin (1982), inflated by 27.7 percent to account for indirect energy requirements, and is equal to 0.64 GJ/ha., or 2.56 GJ for the four applications. The total

TABLE 5.12

ENERGY INPUTS TO BIOMASS PRODUCTION UNDER ALTERNATIVE MANAGEMENT SYSTEMS

Operation	Energy Inputs (GJ/ha./a.) 35K	4K
Plowing	0.10	0.04
Discing	0.11	0.05
Cultivating	0.02	0.01
Planting	0.04	-
Fertilizing	0.64	-
Pest control	0.36	0.16
Harvesting	5.02	5.88
Total	6.29	6.14

energy cost for fertilizer (manufacture and application) over the production cycle is 7.08 GJ/ha., which is equal to 0.64 GJ/ha./a. (Table 5.12).

Energy inputs in the form of herbicides were assumed to be the same as those reported in Ouellette-Babin (1982), plus indirect energy requirements associated with application. For manufacture and application, these inputs amount to 2.00 GJ/ha. Over the production cycles for the 35K and 4K systems, the total inputs are assumed to be the same, at 4.00 GJ/ha. On a yearly basis, this is equal to 0.36 GJ/ha./a. for the 35K system and 0.16 GJ/ha./a. for the 4K system.

Under the 35K system, energy inputs to harvesting are required for the operation of a modified corn harvester, hauling of the biomass to the roadside, and loading of the trucks. Energy requirements for the operation of the harvester are based on those reported by Ouellette-Babin (1982) for a corn combine harvester. The value quoted by Ouellette-Babin was inflated by 30 percent, however, to account for the fact that harvesting of plantation biomass is slower than for agricultural crops (Pfeiffer, 1978). The 30 percent inflation factor was chosen arbitrarily. The resulting coefficient is 0.58 GJ/ha./a.

Energy requirements for hauling and loading trucks are taken from Ash et al. (1980) and are valued at a total

of 3.35 GJ/ha./a. Total direct energy inputs are therefore equal to 3.93 GJ/ha./a., to which is applied a factor of 1.277 to account for the indirect energy requirements for harvesting. Total energy requirements, both direct and indirect, for the harvesting of biomass from a 35K plantation system are valued at 5.02 GJ/ha.

For harvesting under the 4K system, energy inputs are required for tree-felling, hauling of the biomass to the roadside, chipping of the wood, and blowing the chips into trucks. Based on Ash et al. (1980), the total energy requirements (direct and indirect) for these operations is estimated to be 5.88 GJ/ha./a. The total energy inputs for site preparation, planting, fertilizing, pest and disease control and harvesting are 6.29 GJ/ha./a. for the 35K system and 6.14 GJ/ha./a. for the 4K system (Table 5.12).

The other major energy cost associated with biomass production is transportation. A method to estimate energy used in transporting biomass has been developed by Ash et al. (1980). A set of equations is used to estimate energy used in vehicle production, vehicle maintenance, road maintenance and the actual transporting of the biomass.

Calibrating these equations for a 30 tonne capacity vehicle, the same capacity vehicle for which the previously estimated transport costs were quoted (see Section 5.3.2), the system of equations reduces to the following simple linear function (Ash et al., 1980):

$$e^t = 8,157 + 5,168D_L + 2,015D_H, \qquad 5.11$$

where e^t is the total amount of energy, measured in KJ/tonne, used to transport biomass,

D_L is the distance travelled on logging roads, and

D_H is the distance travelled on highways.

Without information on the respective distances travelled on unpaved and paved roads, all transportation is assumed to be on highways, and D_L is set to zero. To estimate energy used in transportation of biomass from each township to Cornwall, on a per hectare basis and for each management system, the following modified form of equation 5.11 was used:

$$e^t_{ij} = [8,175 + 2,015D_H] \cdot Y_{ij} , \qquad 5.12$$

where e^t_{ij} is the transportation energy coefficient for township i and management system j, expressed in KJ/ha./a.

Estimates of the energy used annually in transporting biomass from each township and for each management system are presented in Appendix D.

Total energy used in production of biomass under each management system and for each township (e^{pn}_{ij} in

equation 5.10) is simply the sum of the annual per hectare energy inputs reported in Table 5.12 and the transportation energy coefficients. The coefficients expressing total per hectare energy requirements for biomass production under each management system (e_{ij}^{pn}) are reported in Table 5.13.

Energy in biomass, as noted previously, is assumed to equal 20 GJ/ODt. Thus, annual energy output per hectare from the 35K system is 320 GJ and 167 GJ for the 4K system. Estimates of net energy (energy out minus energy in) for each township and each management system are also reported in Table 5.13.

Energy inputs are clearly rather insignificant in relation to energy outputs from the plantation systems. The energy yield ratios (outputs divided by inputs) are higher than 40:1 in some cases and, at worst, are around 20:1. These estimates graphically illustrate the tremendous energy subsidies provided by natural environmental processes.

These natural energy subsidies are typical of most energy resources. The energy required to extract coal or oil is usually less than the energy embodied in the resource, which is a product of natural processes. The important difference is that in a biomass energy system, the natural subsidies are continuously renewable. Once coal and oil resources are exploited, the natural environmental subsidies required to produce these energy resources

TABLE 5.13

NET ENERGY VALUES FOR BIOMASS PRODUCTION IN EASTERN ONTARIO UNDER ALTERNATIVE MANAGEMENT SYSTEMS

Township	35K System		4K System	
	Energy Inputs (GJ/ha./a.)	Net Energy (GJ/ha./a.)	Energy Inputs (GJ/ha./a.)	Net Energy (GJ/ha./a.)
Dundas Co.				
Matilda	8.05	311.95	7.06	159.94
Mountain	8.27	311.73	7.18	159.82
Williamsburgh	7.60	312.40	6.82	160.18
Winchester	7.91	312.09	6.98	160.02
Glengary Co.				
Charlottenburgh	6.96	313.04	6.49	160.51
Kenyon	7.46	312.54	6.75	160.25
Lancaster	7.41	312.59	6.72	160.28
Lochiel	7.78	312.22	6.92	160.08
Grenville Co.				
Augusta	9.01	310.99	7.56	159.44
Edwardsburgh	8.53	311.47	7.31	159.69
S. Gower	8.63	311.37	7.36	159.64
Oxford	8.87	311.13	7.48	159.52
Wolford	9.33	310.67	7.73	159.27
Prescott Co.				
Alfred	8.40	311.60	7.24	159.76
Caledonia	8.00	312.00	7.03	159.97
E. Hawkesbury	8.23	311.77	7.15	159.85
W. Hawkesbury	8.32	311.68	7.20	159.80
Longueuil	8.42	311.58	7.25	159.75
N. Plantagenet	8.39	311.61	7.23	159.77
S. Plantagenet	7.95	312.05	7.01	159.99
Russell Co.				
Cambridge	7.92	312.08	6.99	160.01
Clarence	8.45	311.55	7.27	159.73
Russell	8.16	311.84	7.12	159.88
Stormont Co.				
Cornwall	6.80	313.20	6.41	160.59
Finch	7.60	312.40	6.82	160.18
Osnabruck	7.19	312.81	6.61	160.39
Roxborough	7.35	312.65	6.69	160.31

cannot be captured again for thousands of years.

In a biomass energy system, the only energy inputs that are permanently lost are those which have been quantified above, and even then this is only the case if these inputs were derived from the expenditure of fossil fuels. The latter is assumed to be the case and those items quantified are considered to be real energy costs. Other energy embodied in harvested biomass, however, is renewable and is not regarded to be a cost. For this reason, the natural energy embodied in the biomass is not included in the calculation of net energy for the total system (equation 5.10).

A final point with respect to energy efficiency in biomass production is that the estimates arrived at here tend to be considerably higher than those arrived at elsewhere. In one of the most extensive studies of biomass plantations in the U.S., for example, Inman et al. (1977) calculated energy yield ratios of between 10:1 and 15:1. The difference between these estimates and those arrived at here is largely accounted for by the fact that the plantations considered by Inman et al. require irrigation, which is not included as a production input in this study. Irrigation accounts for more than one third of total energy inputs accounted for by Inman et al. A second difference of note is that the energy value of wood is assumed to be greater in this study (8,600 BTUs/lb. versus 8,500

BTUs/lb.).

Estimation of the net energy coefficients for the conversion processes are considerably less involved than those for biomass production. For the co-generation facility, there are only two major energy inputs apart from the biomass. These are the energy required for the construction and maintenance of the physical plant and the energy required during plant shutdowns. Ash et al. (1980) suggest that capital and maintainance energy represents approximately 1.5 percent of the feedstock converted. For a 9MW facility, this amounts to about 36,500 GJ annually (Table 5.14). During turbine outage, 185,000 KWH of electricity must be purchased annually, and this amounts to a further input of 666 GJ. Total energy inputs, therefore, equal 37,115 GJ/a. Gross annual output from the facility is 1.62×10^4 GJ. Net energy output as a ratio of wood inputs is therefore equal to 13.03 GJ/ODt (Table 5.14).

For the methanol plant, the same ratio of capital energy to feedstock requirements is assumed. This energy input amounts to 171,391 GJ on an annual basis for the 1,000 tpd facility (including both wood and methane as inputs). Energy to perform the plant operations amounts to a further 79,200 GJ annually (Table 5.14).

A crucial question relates to whether the energy value of the methane should also be included as an input. If the methane is obtained from natural gas, then the total

TABLE 5.14

ENERGY INPUT/OUTPUT RELATIONSHIPS FOR BIOMASS CONVERSION FACILITIES

A. 9MW Co-Generation Plant

	Energy Inputs (GJ/a.)
Capital and maintenance	36,449
Electricity	666
Total	37,115
Plant output	1.62×10^4 GJ/a.
Net output	1.58×10^4 GJ/a.
Net energy per unit of input	13.03 GJ/ODt

B. 1,000 tpd Methanol Plant

	Energy Inputs (GJ/a.) A	B
Capital and maintenance	171,391	171,391
Power	79,200	79,200
Methane from natural gas	8,923,266	-
Methane from solid waste	-	2,700
Total	9,173,857	253,291
Plant output	7.45×10^4 GJ/a.	
Net output	A: -1.72×10^4 GJ/a.	
	B. 7.20×10^4 GJ/a.	
Net energy per unit of input	A. -13.78 GJ/ODt	
	B. 57.51 GJ/ODt	

C. Institutional Heating

	Energy Inputs (GJ/a.)
Capital and maintenance	710
Total	710
Plant output	3.69×10^4 GJ/a.
Net output	3.62×10^4 GJ/a.
Net energy per unit of input	15.30 GJ/ODt

energy value of the methane should be included, since natural gas is a non-renewable fuel. In this case, the input is equal to almost 9 million GJ annually. Total gross energy output is 7.45 x 10^4 GJ, and net output would be approximately -1.7 x 10^4 GJ. This is equivalent to -13.78 GJ/ODt of biomass input (Table 5.14).

On the other hand, if the methane were obtained from a municipal solid waste conversion facility, this could reasonably be construed to be a renewable energy source. Only energy inputs to the conversion of the solid waste would then be relevant, and these amount to only about 2,700 GJ/a. Net energy for the methanol facility is then equal to 7.20 x 10^4 GJ annually, or 57.51 GJ/ODt (Table 5.14). Both alternatives are considered in the analysis described in Chapter 6.

A further issue of interest ~~relating~~ to the energy efficiency of the methanol facility concerns the possibility of a wood-only feedstock alternative. In Section 5.3.3, it was noted that production costs under this alternative were somewhat higher than for a wood-methane plant. By not including the total energy value of the biomass, however, the wood only alternative would have a much greater energy efficiency than the wood-methane alternative, assuming the methane is from natural gas. This contradicts the historical relationship between energy and economic values, but is easily explained by the fact that

the full energy value of the biomass is not included. If the full energy value of the biomass was accounted for, the wood only alternative would be both less economically and less energy efficient than the wood-methane hybrid, even when the methane is obtained from natural gas.

The institutional heating facility has energy inputs only in the form of capital and maintainance energy. At 1.5 percent of the biomass processed annually, this input is equal to 710 GJ/a. (Table 5.14). Gross energy output is estimated to be 3.69×10^4 GJ/a., and net energy is therefore equal to about 3.62×10^4 GJ/a. This is equivalent to 15.30 GJ/ODt of biomass input (Table 5.14).

5.3.7 Environmental Quality

A detailed listing of the environmental impacts that may be associated with the development of biomass energy systems is presented in Chapter 2. Since the types of environmental disruption associated with biomass production are quite different from those that may result from conversion processes, separate goals are defined for each. The goals are specified mathematically as:

$$\sum_i \sum_j [\, a_{ij} \, s^p_{ij} \,] + d^-_6 - d^+_6 = S^p. \qquad 5.13$$

Objective Function: Min. d^+_6;

and

$$\sum_h [\, s_h^c \, q_h \,] + d_7^- - d_7^+ = S^c. \qquad 5.14$$

Objective Function: Min. d_7^+,

where s_{ij}^p is a measure of the environmental disruption per hectare caused as a result of poplar cultivation in township i, under management system j,

S_i^p is a target expressing the acceptable level of environmental disruption as a consequence of poplar cultivation,

s_h^c is a measure of the environmental disruption caused annually per oven dried tonne of biomass processed in conversion facility h, and

S^c is a target expressing the acceptable level of environmental disruption as a consequence of energy conversion processes.

For both goals, the main concern is to minimize environmental disruption beyond the specified target levels. Levels of environmental disruption below the targets are quite acceptable, however. For each of these

goals, therefore, the corresponding positive deviation variable is included in the objective function, while the negative deviation variable is excluded.

The fact that there are multiple pollutants from both biomass production and energy conversion processes poses some difficulties for goal specification, since pollutants are measured in different units. One possibility would be to convert all measures to a common metric. This might be achieved by applying a numerical weighting system which reflects perceptions as to the relative severity of environmental damage caused by each pollutant. Alternatively, separate goals could be specified for each of the major pollutants and the goals then ranked within the model.

Unfortunately, the absence of information on the extent of environmental disruption caused as a result of biomass production and energy conversion processes precluded complete specification of the environmental component of the model. In terms of biomass production, the only data considered to be reliable pertains to soil erosion from potential biomass plantation sites in Eastern Ontario. Soil erosion, as noted in Chapter 2, is potentially one of the most serious environmental hazards associated with energy forestry. Given that data were available and that soil erosion is perceived to be potentially a serious problem, a goal of the form

represented by equation 5.13 is incorporated in the model, which relates to soil erosion. If data were available on other types of environmental disruption caused by biomass plantations, corresponding goals could be included.

A procedure described by Shelton et al. (1984) was followed in order to estimate the coefficients relating to soil erosion from biomass plantations. A set of "erodibility coefficients" were developed for Ontario, based on the Universal Soil Loss Equation (USLE). This equation is defined by Shelton et al. (1984) as:

$$A = R.K.L.S.C.P, \qquad 5.15$$

where A is the potential long term average annual soil loss in tonnes per hectare per year,

R is a rainfall factor, an index which compares the relative energy and intensity of rainfall in one area to that in all other areas,

K is the soil erodibility factor, a measure of a soils' inherent resistance to water erosion,

L is the slope length factor, which indicates the effect of slope length on erosion,

S is an index which incorporates the contribution of slope steepness to runoff and erosion,

C is the cropping-management factor, expressed as a ratio of the amount of soil loss from sheet and rill erosion that would occur under a specified crop and management system to the amount of soil loss that would occur on the same land if it were kept in a continuous fallow state, and

P is the support practice factor, which is the ratio of soil loss in the presence of a specific support practice to the corresponding loss with up-and-down slope cultivation.

The Generalized Soil Landscape Maps of Ontario delineate areas that are generally homogeneous with respect to soil texture, genetic materials, soil development, surface form and slope gradient. Shelton et al. (1984) were able to estimate the K, L and S factors for areas within Ontario on the basis of these maps. The corresponding rainfall factors for the areas delineated on the maps were estimated on the basis of information from climate stations throughout the province.

Shelton et al. (1984) sought to identify potential erosion rates for regions in Ontario, under current land-use practices. Land-use patterns throughout the province were determined using 1981 farm census data. By

overlaying land use maps and the Generalized Soil Landscape Maps, it was possible to identify land use practices within each of the map units. Multiplying the appropriate C-values for land uses by the product of the physical indices (K, L, S and R), Shelton et al. were able to estimate potential erosion in each map unit of the Generalized Soil Landscape Maps. In the absence of information, Shelton et al. set P to 1.0 for all areas.

The objective here is to estimate potential erosion rates from biomass plantation sites in Eastern Ontario. This involved first overlaying a map of the Eastern region on the Generalized Soil Landscape Maps. From the information presented in Shelton et al. (1984), it was then possible to identify the appropriate K, L, S and R indices for each township. The P index is also set to 1.0 in this case. To estimate potential erosion from biomass plantation sites, it remained only to apply the appropriate C-values. Soil loss from the 35K plantation system is expected to occur at similar rates to that from corn fields (Coleman, 1984). The appropriate C-value is 0.250. For the 4K system, the appropriate C-value is that for woodlands, 0.004. Estimates of potential annual per hectare erosion from biomass plantations in each township and for each management system are presented in Table 5.15. These values correspond to the s_{ij}^{p} coefficients within this version of the model.

TABLE 5.15

POTENTIAL SOIL EROSION FROM FOREST ENERGY PLANTATIONS IN EASTERN ONTARIO

Township	Potential Erosion (t/ha./a.) 35K	4K
Dundas Co.		
Matilda	4.55	0.07
Mountain	5.66	0.09
Williamsburgh	6.45	0.10
Winchester	5.58	0.09
Glengary Co.		
Charlottenburgh	8.06	0.13
Kenyon	7.44	0.12
Lancaster	6.18	0.10
Lochiel	8.19	0.13
Grenville Co.		
Augusta	7.67	0.12
Edwardsburgh	2.31	0.04
S. Gower	5.05	0.08
Oxford	4.95	0.08
Wolford	8.01	0.13
Prescott Co.		
Alfred	2.06	0.03
Caledonia	1.93	0.03
E. Hawkesbury	5.54	0.09
W. Hawkesbury	7.75	0.12
Longueuil	1.74	0.03
N. Plantagenet	1.27	0.02
S. Plantagenet	2.03	0.03
Russell Co.		
Cambridge	2.08	0.03
Clarence	0.86	0.01
Russell	3.86	0.06
Stormont Co.		
Cornwall	8.34	0.13
Finch	4.65	0.05
Osnabruck	7.88	0.08
Roxborough	4.21	0.04

Goals relating to environmental disruption caused by biomass energy conversion could not be incorporated in the model, due to the absence of adequate data. Limited information is available on emissions from wood-fired boilers. Table 5.16, for example, compares expected emissions from a 50MW wood-fired electricity generating plant with emissions from conventional fossil fuel plants. Emissions of carbon monoxide and particulates from the combustion of wood are substantially higher than those from coal or oil systems. The emissions of sulphur dioxide, though, are considerably lower for a wood-fired system. The Office of Technology Assessment (1980) notes that all emissions can be significantly reduced through the use of pollution control devices.

Obtaining information on emissions from methanol plants poses the greatest difficulties. The conversion of biomass to methanol has not attracted the same interest in the U.S. as it has in Canada and, thus, research on the environmental impacts of methanol production has not been a priority there. Although there has been greater interest in methanol production from biomass in Canada, research on the environmental impacts of biomass conversion processes has been at best superficial.

The Office of Technology Assessment (1980) provides a comparison between emissions from a wood gasifier to those from wood and oil boilers (Table 5.17). Since

TABLE 5.16

AIR EMISSIONS FOR COAL, OIL AND WOOD FUEL POWER GENERATION

Fuel System	Emissions from a 50MW Plant (t/a)			
	SO_2	CO	Particulates	Total Organic
Low-sulphur Western coal	2,417.5	79.1	102.6	23.4
Crude oil	775.0	-	73.3	14.7
Wood	108.4	361.9	307.7	361.9

Source: Office of Technology Assessment, 1980.

TABLE 5.17

AIR EMISSIONS FROM GASIFIERS, WOOD BOILERS AND OIL BOILERS

Facility	Emissions (kg/hour)			
	CO	NO_x	Particulates	Hydrocarbons
Gasifier	0.0	0.2	0.3	0.4
Wood boiler	0.8-2.5	4.1	2.0-6.1	28.6
Oil boiler	0.2	0.7	0.1	0.1

Source: Office of Technology Assessment, 1980.

methanol is produced by gasification of biomass, emissions from a gasifier are representative of those from a methanol plant (Plotkin, 1980). The comparison suggests that methanol production may involve considerably lower emissions than wood-fired electricity plants or institutional heating.

Table 5.17 does not, however, provide a basis for developing pollution coefficients for this model. No indication is given on the capacity of the plants to which these estimates apply. Moreover, the Office of Technology Assessment (1980) suggests caution in interpreting these figures and recommends that they not be extrapolated to other situations.

In the absence of information on emission rates from methanol facilities, and with only speculative estimates for electricity generation, the environmental component for biomass conversion could not be specified in the model at this time. If data were available, goals relating to environmental disruption that results from energy conversion could be accommodated within the model, and would probably be expressed in the form represented by equation 5.14.

5.3.8 Discussion

The data base that has been developed for the purposes of applying a goal programming system to assess resource development issues, as they relate to the forest biomass energy project, is limited in several respects. Data limitations can largely be attributed to the fact that refinement of many of the coefficients demands the close attention of experts in the relevant fields. In many cases, therefore, there was no option other than to resort to the published information. Recognizing these problems, the use of a goal programming framework is even more appropriate in that it offers opportunities to investigate the uncertainties in coefficients and their impacts on model solutions.

At this juncture it is also appropriate to consider issues relating to the specification of the various goal constraints. For each of the goals listed above, only one measure of goal achievement has been proposed. In many cases, though, alternative measures might have been adopted, and the goals specified accordingly.

In terms of economic efficiency, for example, the criterion used here is revenues minus costs. This is a widely accepted measure of economic viability and was chosen since it was relatively straightforward to

incorporate within the model. Other measures, such as the internal rate of return or benefit-cost ratios, might also have been used, however. Similarly, the energy efficiency goal might have been expressed in terms of energy yield ratios or some other criterion.

The important issue is that model solutions might differ quite substantially if alternative measures of achievement were used. This is an inherent characteristic of any evaluation system and is not unique to goal programming. Alternative expressions of development concerns should, quite reasonably, result in different solutions. Appropriate caution must be exercised, however, when the original development concern is expressed imprecisely, such as "economic efficiency". This can be measured in many different ways, with goals expressed accordingly, and model solutions will probably differ depending on the measure of goal achievement chosen. In presenting the model and the corresponding results, therefore, it must be clearly acknowledged that the original development criteria, economic efficiency, for example, is expressed in the model in a specific way, and that alternative expressions of the general development concern may lead to different solutions.

5.4 SUMMARY

The hybrid poplar plantation program lends itself well to resource assessment analysis. Multiple goals exist, but there is limited knowledge of the potential for hybrid poplar-based energy systems to contribute to the various socio-economic and regional development goals that have been identified here.

This chapter has been devoted to the presentation of the goal programming model and a description of its calibration. A summary of the goal programming model is presented in Table 5.18. The technical/resource constraints, which refer to land availability, total annual biomass supply and permissible sizes for the conversion facilities, are represented in the upper portion of the table. The model allocates land resources to biomass production under alternative management systems and, simultaneously, allocates the biomass produced annually to energy conversion processes, subject to the constraints listed and such that a prioritized set of goals is best satisfied. Accordingly, the goals, listed in the lower portion of the table, refer both to biomass production and energy conversion phases of the proposed energy development.

All goals require that regional targets be specified. The goal relating to economic efficiency in

TABLE 5.18

GOAL PROGRAMMING MODEL FOR RESOURCE ASSESSMENT IN EASTERN ONTARIO: SUMMARY FORMULATION

GOAL/CONSTRAINT DESCRIPTION	BIOMASS PRODUCTION COEFFICIENTS Decision variable: a_{ij}, for $i = 1, \ldots, 27$, $j = 1,2$.	ENERGY CONVERSION COEFFICIENTS Decision Variable: q_h, for $h = 1,2,3$.	
Resource/Technical Constraints			*Right-hand-side*
Land Availability	$\sum_j a_{ij}$		$\leq A_i$
Biomass Supply	$-\sum_i \sum_j \left[\frac{v_{ij}\, a_{ij}}{o_j} \right]$	$-\sum_h [q_h]$	$= 0$
Conversion Facility Size		q_h	$\leq q_h^U$, $\geq q_h^L$ or $= q^*$, or $= 0$
Goal Constraints			*Goal Target*
Economic Efficiency in Biomass Production	$\sum_i \sum_j \left[\left(\sum_{t=0}^{I_j} \frac{R_{ijt} - C_{ijt}}{(1+r)^t} \right) I_j^{-1} \right] a_{ij} + d_1^- - d_1^+$		$= V^P$
Economic Efficiency in Energy Conversion		$\sum_h (R_h - C_h)\, q_h + d_2^- - d_2^+$	$= V^C$
Regional Employment Generation	$\sum_i \sum_j [a_{ij}\, l_{ij}^P]$	$+ \sum_h [q_h\, l_h^C] + d_3^- - d_3^+$	$= L$
Regional Income Generation	$\sum_i \sum_j [a_{ij}\, m_{ij}^P]$	$+ \sum_h [q_h\, m_h^C] + d_4^- - d_4^+$	$= M$
Energy Efficiency	$-\sum_i \sum_j [e_{ij}^{pn}\, a_{ij}]$	$+ \sum_h [(e_h^{co} - e_h^{cn})\, q_h] + d_5^- - d_5^+$	$= E$
Environmental Quality-Biomass Production	$\sum_i \sum_j [a_{ij}\, s_{ij}^P] + d_6^- - d_6^+$		$= S^P$
Environmental Quality-Energy Conversion		$\sum_h [q_h\, s_h^C] + d_7^- - d_7^+$	$= S^C$

biomass production, for example, is expressed in terms of a target level for total regional receipts, rather than returns to individual land owners or units of land. Similarly, the goal for employment generation collectively accounts for employment in both biomass production and energy conversion, over the entire region.

The deviation from the target which is to be minimized (ie., either the positive or negative deviation) depends upon the specific goal under consideration. In the case of regional income, for example, the major concern is to minimize the extent to which the amount of income generated falls short of the target value, whereas over-achievement is acceptable. Only the negative deviation variable is therefore included in the objective function of the model. For each goal constraint, the deviation variable to be minimized, and which is therefore included in the objective function, has been italicized in the table.

Even in the absence of analysis based on the goal programming model, the exercise of formulating the model and calibrating the various equations provides information that is of considerable value. In formulating the model, development goals must be expressed precisely. Moreover, the essential factors that will influence development goals (as transportation costs affect returns to biomass production) are clearly identified. Calibration then defines the various relationships in quantitative terms.

The model, therefore, provides a detailed perspective on the development proposal at hand.

Two additional types of information are required to complete specification of the model. For each goal, target levels must be specified. Priority orderings of the goals must also be established prior to the running of the model. Detailed consideration of these two very important components is reserved until the following chapter.

The goal programming model described above has been designed to permit systematic assessments of the proposed plantation forest development, relative to a diverse set of criteria, which are expressed in disparate metrics. In several respects, the data bases that have been developed are deficient. Despite this, application of the model will not only be a useful exercise by which to further evaluate the utility of goal programming systems for resource assessment, but will also provide interesting insights into the implications for the region of this resource development project. The following chapter discusses implementation of the model and summarizes the results obtained.

CHAPTER 6

THE RESOURCE ASSESSMENT ANALYSIS

6.1 INTRODUCTION

Goal programming has been identified as a method that potentially has the capability to address questions that are fundamental in resource assessment. In the previous chapter, a goal programming system was developed to assist resource assessment analysis in the context of forest energy developments in Eastern Ontario. The application of the system for the purposes of resource assessment is described in this chapter.

Implementation of the goal programming system provides useful insights into the possible social, economic and environmental implications of plantation forestry developments. At the same time, practical experience with the method provides a better basis on which to evaluate the capabilities of goal programming for resource assessment in general. The emphasis is on demonstrating, by example, the various ways in which the model can be applied to address questions pertinent to resource assessment and in

illustrating the nature of the information provided.

The following section provides an outline of the stages in the analysis. Results of the resource assessment analysis are then presented in detail. The final section of the chapter draws together the major findings with respect to forest energy developments in Eastern Ontario.

6.2 STRATEGY OF THE ANALYSIS

The first component of the analysis is concerned with target setting. Goal targets are an essential component of model specification and the method by which these were established for the Eastern Ontario resource assessment model is described. The procedure followed provides additional information in the form of the potential maximum attainment levels for each of the specified goals.

Following this, analysis is devoted to identifying goal achievement levels, under different priority orderings. This information is required to address both the first and third questions pertinent to resource assessment, which, respectively, refer to the potential to achieve specified targets and the effects upon target achievement of variations in goal priority orderings. At the same time, this analysis provides a basis for determining goal relationships. At least partial answers are therefore

provided in terms of those questions relating to goal conflicts.

The sensitivity of goal programming solutions to changes in the specified target levels has previously been noted, and it was anticipated that adjusting target levels may affect the goal relationships identified. Consequently, analysis was then directed at assessing the effects upon goal relationships and resource allocations of changes in the specified target levels for the goals.

The last set of results reported on in this chapter was obtained from analysis directed at evaluating the effects on goal achievement levels of changes in selected model coefficients. This analytical component is a response to the second question relevant to resource assessment, which concerns the implications of uncertainties with respect to production relationships, resource limitations and institutional constraints.

A multiple-objective goal programming algorithm developed at Colorado State University was used for the analysis. This algorithm is based on the goal programming simplex method developed by Lee (1972). The program is written in FORTRAN to comply with the American National Standards Institute, and is therefore compatible with a wide variety of computer systems. General user instructions are presented in Bartlett et al. (1976) and technical aspects asspciated with the program are described in Pope

and Bottoms (1976). The program was run on a CDC Cyber, under the NOS operating system.

6.3 TARGET SETTING AND RESOURCE POTENTIAL ANALYSIS

In Chapter 4, it was acknowledged that target levels will have an important effect on model solutions within a goal programming system. The manner in which target levels are established for a goal programming model is therefore of considerable importance. In some instances, decision makers may be able to clearly articulate desired achievement levels for the goals under consideration. This is probably more characteristic of private sector planning than planning in the public sector. In the public sector, decision makers may be less sure of preferences in terms of targets for specific objectives or perhaps unwilling to state desired levels of achievement. Although the adoption of a goal programming model might encourage decision makers to express more precisely their expectations in terms of target levels, it will not always be possible to elicit this type of information. In the absence of explicit information on targets, there are several approaches available to the analyst by which to set goal targets, some of which were discussed in Section 4.4.1.

The approach adopted here for all goals, except that relating to environmental quality, is to identify maximum

levels of achievement for each goal independently, and to use these values as the initial targets. The maximum attainment level for a goal can be identified via the goal programming model by setting the respective goal at the highest priority level and minimizing the negative deviation variable from an unattainable value. The procedure is repeated for each goal to be considered. A similar procedure can be followed to identify minimum possible levels for goals (see Section 4.4.1), but is not relevant to any of the goals included in this model.

Apart from providing a set of target levels for the respective goals, this approach yields information that has value in itself. The calculated target values represent the maximum values that can be achieved for each goal, in the absence of other development priorities, and given the available resources. This can be termed the resource potential for each goal. The resultant values provide an indication of the potential magnitude of achievement levels for individual goals and this information may be of value in resource management decision making. The calculated values serve the additional purpose of representing initial target values for analysis via the goal programming framework. The potential maximums may, however, far exceed desired levels of attainment for goals and, for this reason, the sensitivity of model solutions to changes in target levels must be carefully examined. Sensitivity

analysis in terms of target levels is considered in Section 6.5.

Following the procedure described above, target levels for each of the goals, except environmental quality, were identified and are reported in Table 6.1. Maximum returns to biomass production are achieved under the land allocation pattern illustrated in Figure 6.1. In this case, total biomass produced within the region is equal to 170,831 ODt/a.

Net annual economic returns to energy conversion are maximized by producing the greatest possible quantity of biomass (all land allocated to the 35K system) and assigning the biomass first to the institutional heating complex, with the remainder allocated to co-generation. Total biomass produced annually is 490,344 ODt, of which 2,365 ODt are assigned to institutional heating and 487,979 ODt are assigned to co-generation. Under the assumptions employed here, a co-generation plant processing this quantity of biomass would have a net annual output of approximately 36MW.

Regional employment is maximized by allocating all land in the region to the 35K production system and all biomass produced (490,344 ODt) to the methanol plant. With this quantity of biomass available, a methanol plant of the design considered here would be capable of producing approximately 3,900 tpd of fuel alcohol. Total employment

TABLE 6.1

GOAL TARGET LEVELS IN THE BASE MODEL

Goal	Target Level	Land Allocation 35K	4K
		(ha.)	
Production Economics ($)	1,544,052	13,616	47,677
Conversion Economics ($)	1,688,250	61,293	-
Regional Employment (hours)	961,468	61,293	-
Regional Income ($)	33,194,073	61,293	-
Energy Efficiency (GJ)	5,899,085	61,293	-

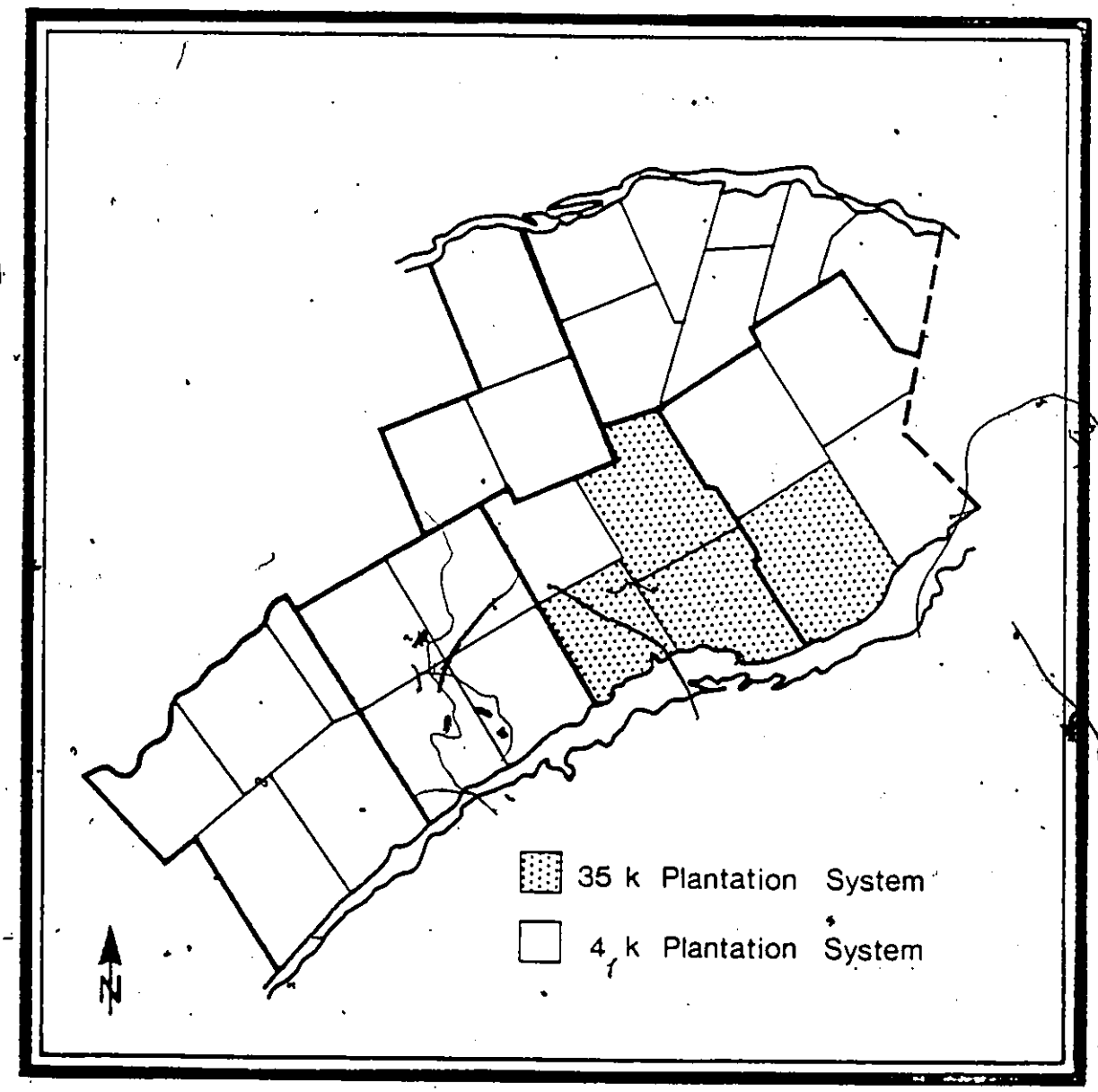


FIGURE 6.1 Land resource allocation pattern that maximizes production economics: Base model.

generated is equal to 961,468 worker-hours per annum, or 462 jobs, assuming 52 40-hour work weeks per year. The same resource allocation maximizes regional income generation.

Net energy output for the biomass energy system is maximized by allocating all land to the 35K plantation system and the biomass produced to the institutional heating complex and co-generation. Total biomass produced and the assignments to end uses are the same as those reported for the goal relating to economic efficiency in energy conversion.

For the environmental quality goal, the target level is the estimated annual rate of erosion from the land if it remained in its idle state. Idle land can be classified as one of two types: land idle for 1-10 years and land idle for more than 10 years (see Section 3.1). An appropriate C-value for the former is that for native grasslands (0.18), while for the latter that for woodlands is appropriate (0.004). The respective areas of land in each land-use category for each township are reported in the FARINEO study (OMAF and OMNR 1982). The annual rate of erosion in the absence of poplar plantations could then be calculated by multiplying the reported acreages by the appropriate erosion coefficients (see Section 5.3.7) and summing over land types and townships. The value so obtained is 93,522 tonnes per annum and this represents the target level for the environmental quality goal.

Analysis associated with the identification of target levels has considered goals independently of each other. This provides useful information in the form of a set of initial target levels to be used in the model and, at the same time, provides measures of the maximum possible attainment levels for the respective goals. The capability to assess the proposed forest energy project relative to multiple goals was, however, a fundamental reason for selecting goal programming as a method of analysis. The powerful capabilities of the model in this respect are demonstrated in the subsequent analyses.

6.4 GOAL RELATIONSHIPS AND GOAL CONFLICT ANALYSIS

The analysis of this section is designed to provide at least partial answers to three of the four questions relevant to resource assessment. The first question refers to the extent to which goals can be achieved, given available resources and taking explicitly into account the relative importance assigned to the achievement of the various goals. Because different perceptions may exist with respect to how important the achievement of one goal is relative to the achievement of the others, another question relates to identifying the effects upon resource assessments of changing the priorities assigned to the various goals. Closely related to this is a third question,

which concerns the nature and extent of goal conflicts.

To answer these questions, alternative priority orderings of the goals were selected and the (base) model run to identify goal achievement levels under different priority structures. For this analysis, alternative priority orderings of the goals were randomly selected. This was a legitimate procedure, given that the primary objective was to identify the trade-offs between goals. By randomly re-ordering the goal priorities, it was expected that the results would eventually indicate which goals are mutually compatible and which goals were in conflict. Although this would be useful information in most planning contexts, there may be cases where priorities regarding goal achievement are more clearly defined. In such cases, the analyst may have less responsibility for establishing goal priority structures.

In the analysis described below, preferences for goal achievement are expressed exclusively via a priority ordering system, in view of the aforementioned difficulties associated with identifying valid numerical weighting schemes. Also in this analysis, no two goals are ever ranked at the same priority level. This again relates to the fact that a primary objective here is to identify goal relationships. When two or more goals are ranked at the same priority level, results may be very difficult to interpret and this procedure would not contribute to

identifying goal conflicts.

Selected results of the analysis are reported in Table 6.2. Each pair of columns represents one scenario. The first column indicates the priority ordering of the goals, where a 1 indicates that the goal is ranked highest and a 6 indicates that the goal is ranked at the lowest priority level in the model. The second column under each scenario presents the results in terms of the level of achievement for the respective goal. The unbracketed values are the absolute achievement levels. In Scenario 1, Table 6.2, for example, the net return to biomass production for the region is approximately $1,540,000. The bracketed value immediately underneath indicates that the specified target, which in this case is the maximum possible return to biomass production, is fully achieved. Full attainment of the biomass production economics goal is achieved under the land resource allocation pattern illustrated in Figure 6.1.

Given that the first priority goal could be fully achieved under Scenario 1, the second priority goal, conversion economics, was considered. The best result that could be achieved with respect to this goal was a net return of approximately $600,000, which is about 36 percent of the $1,688,250 target. Any re-allocation of resources that would improve the result with respect to conversion economics would result in the biomass production target no longer being attainable. Similarly, any re-allocation of

TABLE 6.2

GOAL RELATIONSHIPS IN THE BASE MODEL
SELECTED RESULTS 1

Goal	Scenario 1 Priority	Scenario 1 Goal Level	Scenario 2 Priority	Scenario 2 Goal Level	Scenario 3 Priority	Scenario 3 Goal Level
Production Economics	1	1.54 (100%)	2*	-0.39 (-25%)	4	-0.39 (-25%)
Conversion Economics	2*	0.60 (36%)	1	1.69 (100%)	2*	-25.42 (-1,506%)
Regional Employment	3	0.37 (39%)	3	0.74 (76%)	3	0.96 (100%)
Regional Income	4	7.57 (23%)	4	11.30 (34%)	1	33.19 (100%)
Energy Efficiency	5	1.87 (32%)	5	5.90 (100%)	5	-7.25 (-123%)
Environmental Quality	6	0.10 (90%)	6	0.35 (-172%)	6	0.35 (-172%)

Notes

1. All unbracketed values reported under Goal Level are x 10^4.
2. * indicates priority level at which solution is determined, assuming multiple optima do not exist.

resources that would lead to an improvement in the third priority goal, regional employment, would result in a lower level of achievement for at least one of biomass production economics or energy conversion economics. The allocation of resources which simultaneously allows full achievement of the production economics target and minimizes the deviation from the conversion economics target automatically determines achievement levels for all lower ranked goals, unless multiple optima exist. For Scenario 1, therefore, the solution has been determined at priority level 2, as indicated by the asterisk.

Results from this scenario suggest that maximization of economic returns from biomass production demands considerable sacrifices in terms of the other goals, except environmental quality. Highest returns to biomass production are typically achieved under the 4K plantation system, but production under the 35K system would lead to considerably better results with respect to most of the other development goals, due to the much greater annual productivity.

Under Scenario 2, Table 6.2, the priority ordering of production economics and conversion economics is reversed, so that conversion economics is at the highest priority level. The conversion economics target is now fully achieved. Relative to Scenario 1, improved results are also obtained with respect to regional employment,

regional income and energy efficiency. To attain the maximum possible economic return to energy conversion necessitates that the greatest possible quantity of biomass be processed. As noted in Section 6.1, the maximum quantity of biomass will be produced with all land in the region devoted to plantations under the 35K management system. As a result, the region will incur negative net returns to biomass production equal to approximately -$390,000, which is equivalent to a -25 percent deviation from the target. That is, the value obtained is 125 percent smaller than the target value. Also, soil erosion is more than 2.7 times greater than the target value, at almost 350,000 tonnes per annum, and this is expressed as a -172 percent deviation from the target amount.

With the regional income goal at the highest priority level (Scenario 3, Table 6.2), both this and the regional employment goal are fully achieved. Achievement of the regional income goal again necessitates that all land be devoted to the 35K system. To fully achieve the regional income goal also requires that all biomass be assigned to methanol production. As a result, there is a net loss of energy over the entire system. There is also a substantial financial loss incurred in energy conversion.

If all land in the region were devoted to biomass production [illegible] the 4K system, total soil erosion would equal 5,20[illegible] per annum. This is considerably less

than the target level for the environmental quality goal. Land may, therefore, be allocated to biomass production under a very large number of combinations of the two management systems and still satisfy the environmental quality goal. In this sense, the environmental quality goal differs from the others, for which the respective target levels can be achieved under only one resource allocation pattern. With environmental quality ranked at the highest priority level, therefore, alternative combinations of the other goals were tried to further identify potential goal conflicts and to identify further options for resource use. Selected results are presented in Table 6.3.

With economic efficiency in biomass production ranked second to environmental quality (Scenario 1, Table 6.3), the resource allocation pattern is very similar to that represented in Figure 6.1. The only notable difference is that approximately 2,300 ha. of land in Roxborough township are devoted to the 4K management system, where previously all 2,568 ha. were devoted to the 35K system. Consequently, there is a decline in annual biomass production equal to 14,770 ODt. This accounts for the slight declines in achievement levels in all other goals, as compared to the results achieved with the economic efficiency goal at the first priority level (Scenario 1, Table 6.2).

For Scenarios 2 and 3 of Table 6.3, the economic

TABLE 6.3

GOAL RELATIONSHIPS IN THE BASE MODEL
SELECTED RESULTS 2

Goal	Scenario 1 Priority	Scenario 1 Goal Level	Scenario 2 Priority	Scenario 2 Goal Level	Scenario 3 Priority	Scenario 3 Goal Level
Production Economics	2	1.54 (100%)	3	0.43 (28%)	3	0.44 (38%)
Conversion Economics	3*	0.55 (32%)	2*	0.93 (55%)	4	-13.97 (-827%)
Regional Employment	6	0.36 (38%)	6	0.54 (56%)	6	0.66 (69%)
Regional Income	4	7.57 (22%)	4	8.97 (27%)	2*	21.00 (63%)
Energy Efficiency	5	1.68 (28%)	5	3.05 (52%)	5	-4.17 (-70%)
Environmental Quality	1	0.09 (100%)	1	0.09 (100%)	1	0.09 (100%)

Notes
1. All unbracketed values reported under Goal Level are x 10^4
2. * indicates priority level at which solution is determined, assuming multiple optima do not exist.

efficiency in energy conversion and regional income goals are, respectively, ranked second to environmental quality. The resulting land allocations under these two scenarios are very similar to each other, but quite different from allocations previously generated. The allocation corresponding to Scenario 3 is illustrated in Figure 6.2. In each scenario, minimization of the deviation variable for the goal at the second priority level will be achieved by allocating the largest possible quantity of land to the 35K management system. Land assigned to the 35K system is that with the lowest rates of soil erosion, thereby insuring that the environmental quality target is at least satisfied.

Since all land cannot be allocated to the 35K system, there is a decline in the quantity of biomass produced relative to those scenarios in which conversion economics and regional income were each set at the first priority level (respectively, Scenarios 2 and 3, Table 6.2). With energy conversion economics ranked at the second priority level, annual biomass production equals 269,419 ODt, a decline of 220,925 ODt from the production level achieved when the conversion economics goal was at the first priority level. Achievement levels for the regional employment, regional income and net energy goals consequently decline. There is, however, an improvement in terms of regional biomass production economics.

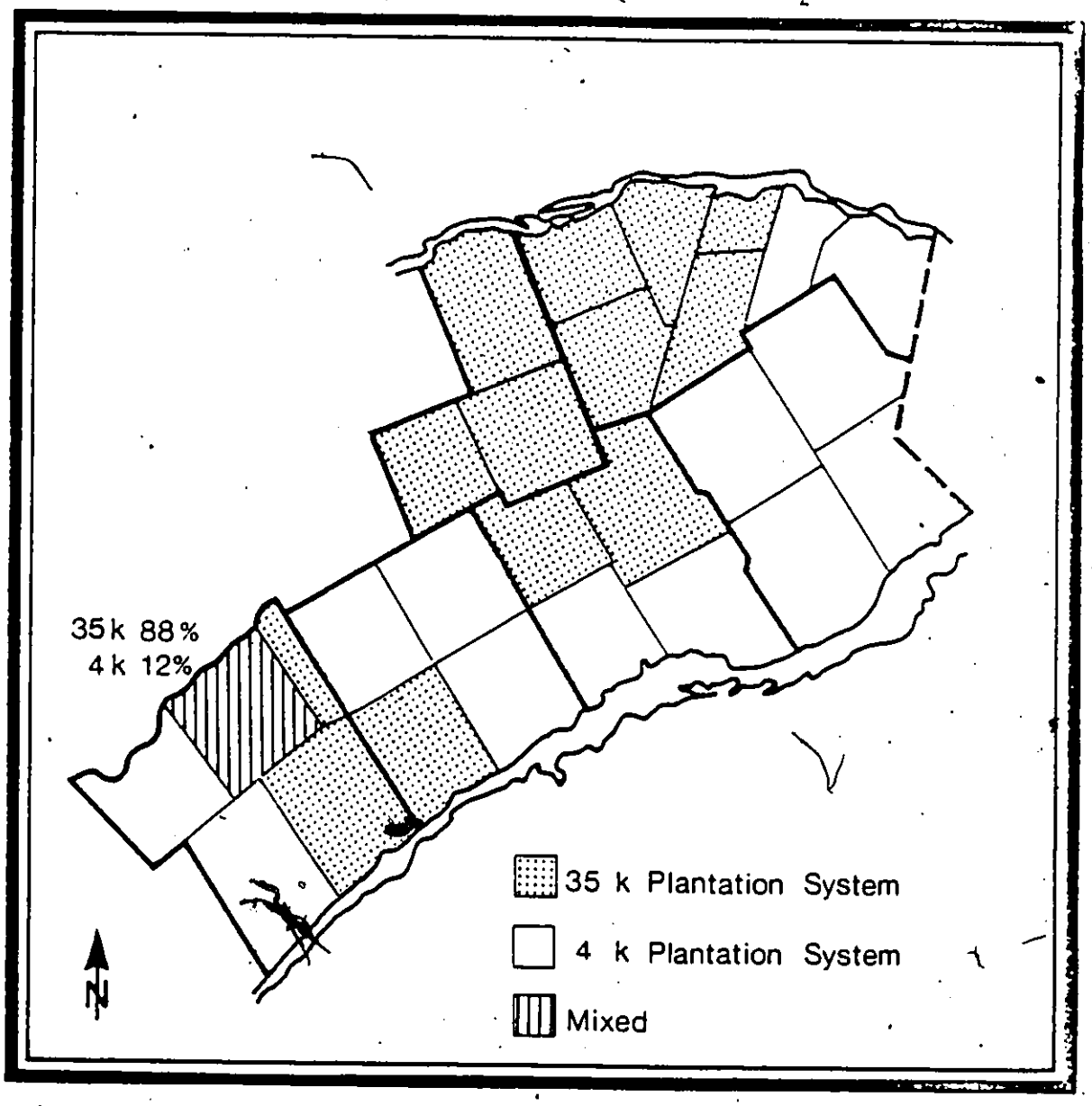


FIGURE 6.2 Land resource allocation pattern with environmental quality at priority 1 and regional income at priority 2.

Compared to the results obtained when regional income was at the highest priority level (Scenario 3, Table 6.2), the ranking of this goal second to environmental quality results in a decline in annual biomass production of 220,997 ODt. Consequently, both the regional income and regional employment goals suffer. With less biomass available to the methanol plant (the preferred end use in terms of regional income generation), the deviation from the energy conversion economics and total energy goals is less than in the case where the regional income goal was ranked at the highest priority level.

From the results presented in Tables 6.1 and 6.2, the nature of goal relationships in terms of hybrid poplar developments are quite distinct. These relationships are summarized in Figure 6.3. Goals linked by solid arrows exhibit a strong mutual compatibility. A resource allocation which permits full achievement of the regional income goal, for example, will also imply a favourable result in terms of regional employment and vice versa. Note that although a favourable result will be obtained with respect to production economics when ranked second to environmental quality (Scenario 1, Table 6.3), resource allocations that favour environmental quality do not necessarily imply favourable results in terms of production economics (see, for example, Scenarios 2 and 3, Table 6.3). Thus, even though a mutually compatible relationship is

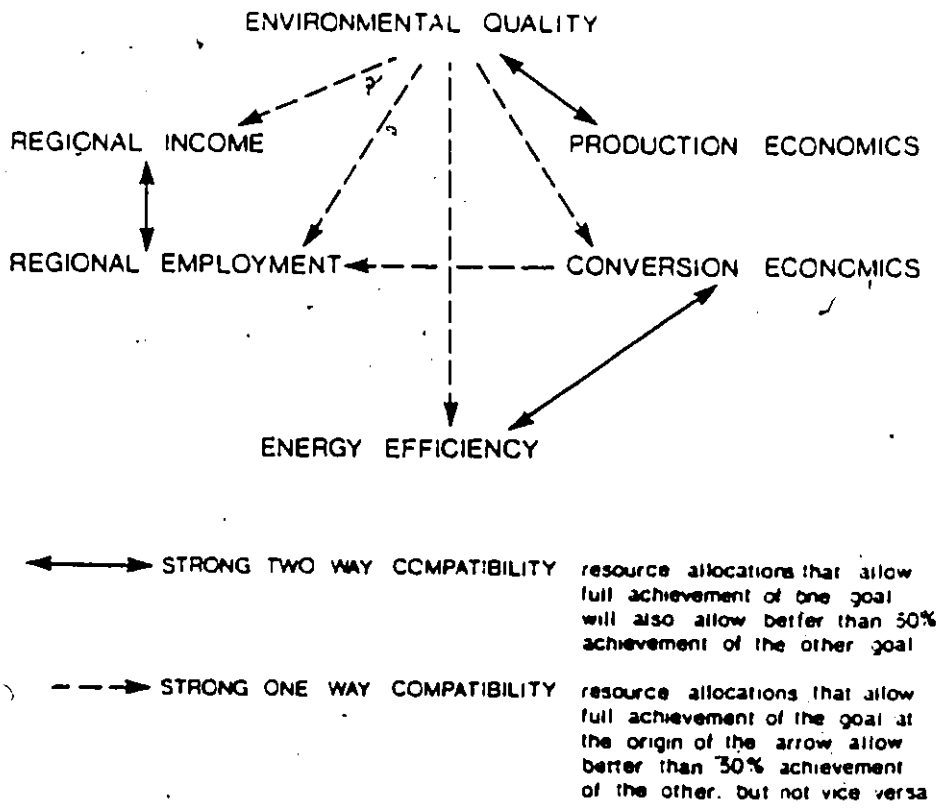


FIGURE 6.3 Goal relationships in the base model.

defined between these goals (Figure 6.3), there are certain circumstances under which this two-way compatibility does not hold.

The one-directional dotted lines indicate a strong one-way compatibility between the goals. A resource allocation that permits maximization of net economic returns to energy conversion, for instance, results in almost an 80 percent achievement level for regional employment (Scenario 2, Table 6.2). Maximization of regional employment, though, would require that all biomass be allocated to methanol production, and this would result in a net financial loss to energy conversion.

Not only can these various goal relationships be identified through this type of analysis, but the results also provide quantitative measures of the extent of conflict between goals. Maximization of net economic returns to energy conversion, for example, means that approximately 220,000 worker-hours (107 jobs) are lost relative to the maximum employment level attainable. Alternatively, maximum employment implies a net financial loss of over $25,000,000, or approximately $27,000,000 less revenue generated through energy conversion operations than the maximum attainable.

Care must be taken, however, in interpreting these measures. The present analysis considers goal conflicts only under conditions where maximum attainment levels for

all goals are sought. In the following section, goal conflicts will be considered further, in the context of alternative target levels for particular development goals.

6.5 THE EFFECTS OF TARGET LEVELS

To this point, the specified target levels for each of the goals have been the respective maximum achievement levels, with the exception of that for environmental quality. Re-specifying target levels serves several important purposes in this study. First, the considerable sensitivity of goal programming solutions to target levels has been previously acknowledged. To investigate this sensitivity within the specific research context is of importance. Second, decision makers may often be prepared to accept attainment levels for specific goals that are less than the maximums, particularly if this implies improved results in terms of other development criteria. Goal programming models can provide useful information in terms of the effects on goal attainment levels and resource allocations as targets for particular goals are changed. At the same time, this type of analysis will provide further insights into the nature of goal relationships, which is of considerable importance in resource assessment.

The effects of target levels on model solutions were first investigated in terms of the goal relating to

economic efficiency in biomass production. Beginning at $125,000, the target level was increased in increments of $125,000 to $1,500,000 and then to $1,544,052, the maximum attainable goal level. This represents a range in average annual net return per hectare for the region of $2.04 to $25.49. Target levels for all remaining goals are those assumed for the base model.

With the production economics goal set at the highest priority level, the implications of these changes in the goal level were assessed under alternative orderings of the other goals. One set of results is illustrated in Figure 6.4. As the target level for production economics is increased, the attainment levels for all other goals decrease, with the exception of environmental quality, for which the attainment level shows a dramatic increase over the range.

At the lower end of the range, land resources are devoted primarily to production under the 35K system (53,913 ha.), which ensures a high level of attainment for the second priority goal, energy conversion economics. All of the biomass produced is allocated to institutional heating and the co-generation plant. With increases in the target level for production economics, more land must be allocated to the 4K system, because of its typically higher per unit area returns. Consequently, there is a decline in total annual biomass production. At the upper level of the

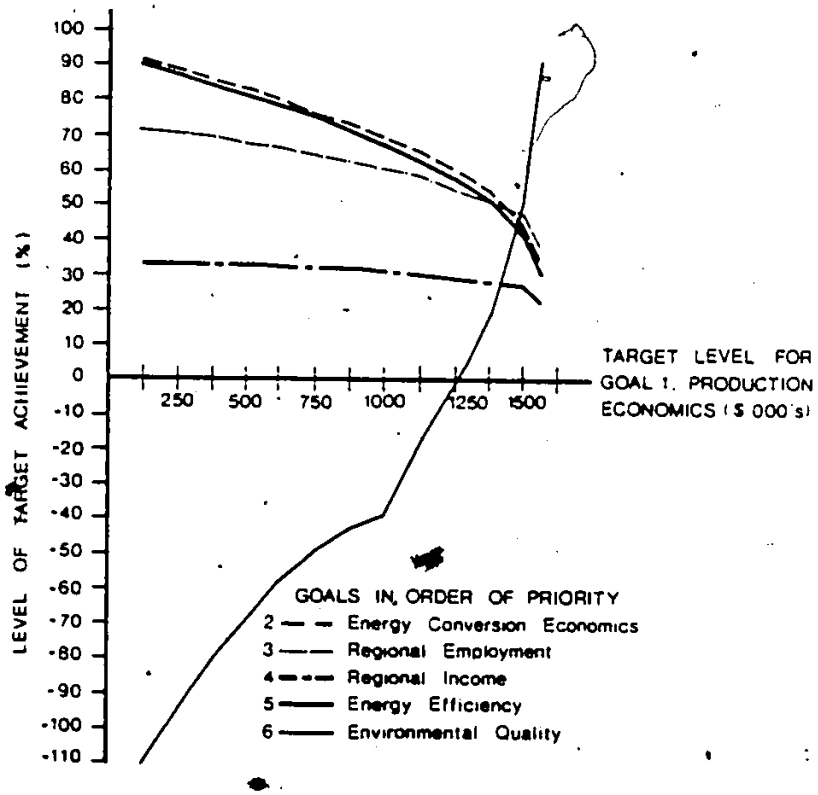


FIGURE 6.4 GOAL RELATIONSHIPS AT ALTERNATIVE TARGET LEVELS FOR PRODUCTION ECONOMICS: EXAMPLE 1

range, land is allocated to the 35K production system in only the four townships closest to Cornwall (see Figure 6.1).

A second example of this analysis is illustrated in Figure 6.5, where regional employment has replaced energy conversion economics at the second priority level. Land resource allocation patterns over the target range are very similar to those described above. In this case, however, all biomass is allocated to the methanol plant. There is a noticeable improvement in attainment levels for regional income, but total net energy and conversion economics are negative over the entire range. Due to the magnitude of the results for conversion economics, they are not illustrated in the figure, but they follow a relatively regular increase from -1,362 percent to -525 percent. The increase over the range is attributable to the fact that less biomass becomes available to the methanol plant as greater quantities of land are allocated to the 4K system.

In a third example, environmental quality is ranked second to biomass production economics. These results are illustrated in Figure 6.6. At all target levels for the first priority goal except the maximum, the environmental quality target can be satisfied. Hence, the resultant resource allocations may be partly affected by the third priority goal, energy conversion economics.

At the lower end of the target range for production

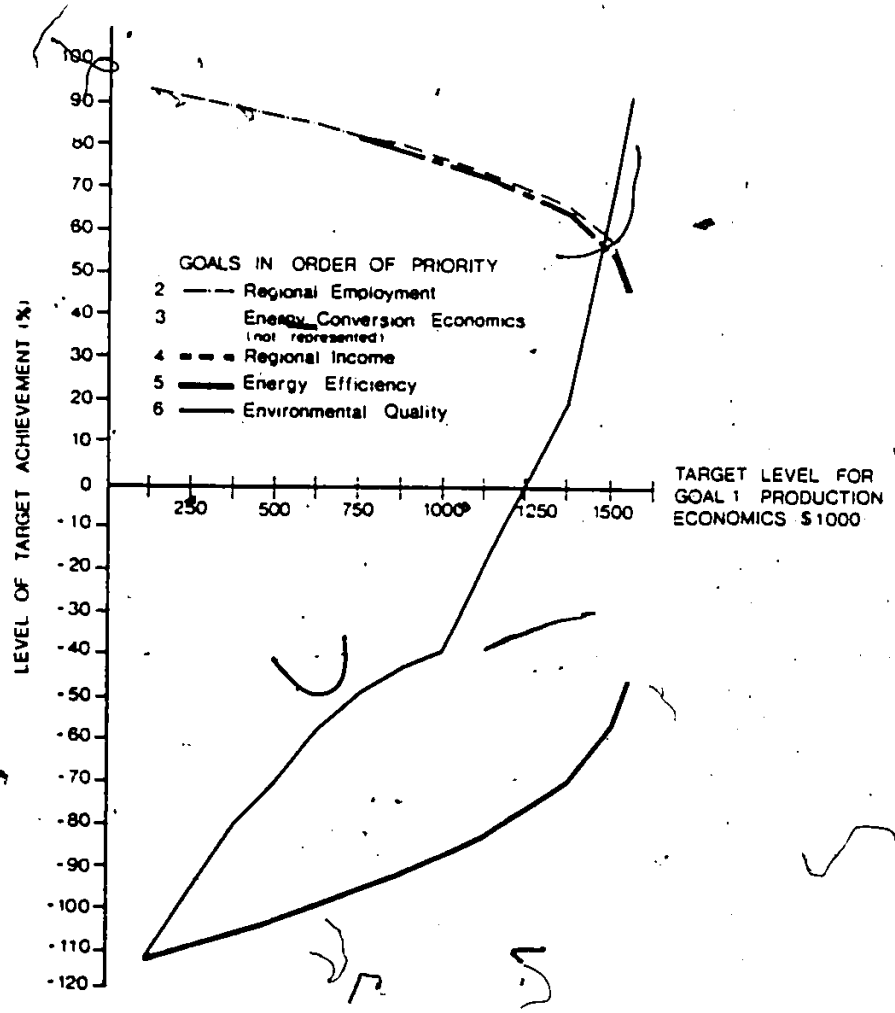


FIGURE 6.5 GOAL RELATIONSHIPS AT ALTERNATIVE TARGET LEVELS FOR PRODUCTION ECONOMICS. EXAMPLE 2

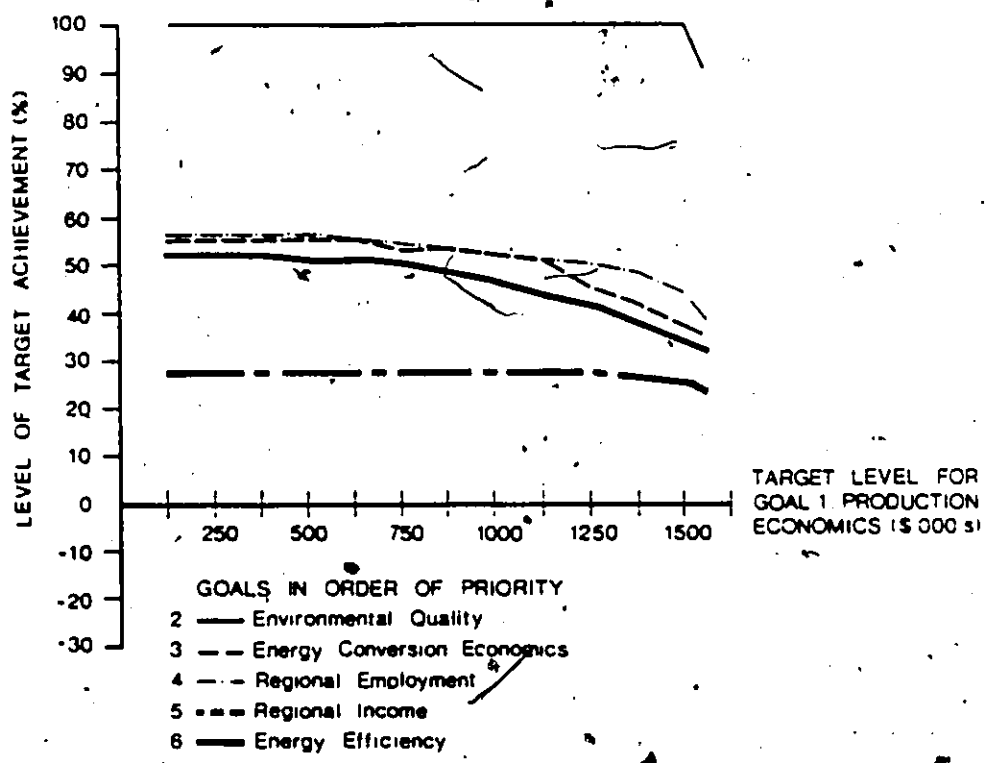


FIGURE 6.6 GOAL RELATIONSHIPS AT ALTERNATIVE TARGET LEVELS FOR PRODUCTION ECONOMICS: EXAMPLE 3

economics, land is allocated to the 35K system to the maximum allowable level without compromising the achievement of the environmental quality goal, thus simultaneously minimizing the deviation from the conversion economics goal. Biomass is allocated to institutional heating and co-generation. As the target level on biomass production economics increases, greater quantities of land must be devoted to the 4K system, a change that is compatible with the environmental quality goal. Attainment levels for the remaining goals, however, gradually decline over the range. At the upper end of the target range, the 35K plantation system is assigned to land in only four townships (see Figure 6.1).

In each of the figures, the curves representing achievement levels for most of the goals assume much steeper slopes as the target level for the production economics goal closely approaches the maximum attainable level (ie., over the range $1,500,000 to $1,544,052). In other words, the marginal rate of change for each goal rapidly increases as the target level on production economics approaches its maximum. Resource allocations that achieve a maximum level in terms of production economics, therefore, may imply much higher costs in terms of other goals, relative to allocations that satisfy only slightly lower target levels for the economic efficiency goal. This may have important implications in designing resource

development strategies.

A similar type of analysis was conducted with the goal relating to economic efficiency in energy conversion now ranked at the first priority level. The target for this goal was increased from a base level of $125,000 in equal increments to $1,625,000 and then to the maximum level of $1,688,250. All other targets are as specified for the base model. As in the previous case, the consequences of these adjustments in the target level were investigated for alternative goal priority structures.

One example is illustrated in Figure 6.7, where the goal relating to economic efficiency in biomass production is ranked second to energy conversion economics. With the target on conversion economics set at a low level, the second priority goal dictates the allocation of management systems to land and the resulting pattern is that illustrated in Figure 6.1. Once the target level on conversion economics reaches $625,000, however, additional quantities of land must be assigned to the 35K system in order that sufficient biomass can be produced within the region. As expected from results obtained previously, with larger areas producing under the 35K system, production economics and environmental quality suffer, while attainment levels for other goals improve. At all target levels for conversion economics, biomass is assigned to the institutional heating and co-generation facilities.

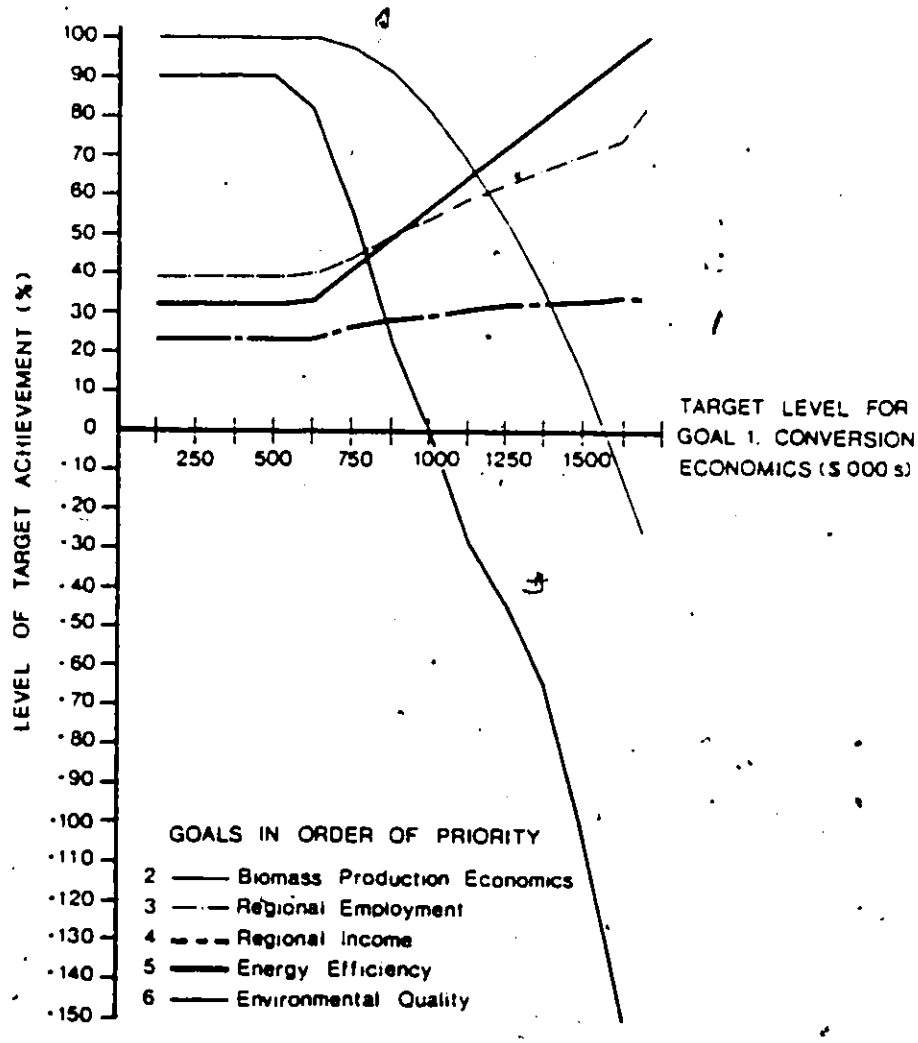


FIGURE 6.7 GOAL RELATIONSHIPS AT ALTERNATIVE TARGET LEVELS FOR CONVERSION ECONOMICS EXAMPLE 1

In a second example, environmental quality is ranked at the second priority level, with conversion economics still at the first priority level. The results are presented in Figure 6.8. In several respects the pattern is generally similar to that of Figure 6.7. Notable differences exist, however. First, observe that the slopes of the curves take on non-zero slopes at a higher target level than previously. This occurs because a much greater area of land is devoted to the 35K system at the lower end of the target range, thereby minimizing the deviation from the third priority goal, regional employment. Since more biomass is produced at the lower target levels than in the previous example, the energy conversion economics target level must rise to a higher level before it becomes necessary to allocate additional land to the 35K plantation system.

The curve representing achievement levels for the biomass production economics goal exhibits a trend previously unseen. The curve declines to a minimum level of -29 percent and then rises to -25 percent achievement as the target on conversion economics is raised to the maximum attainable level. At the $1,600,000 target level, most land in the region must be devoted to the 35K production system in order that the necessarily large quantities of biomass can be produced. The target is not so high, however, that all land must be assigned to the 35K system and the model

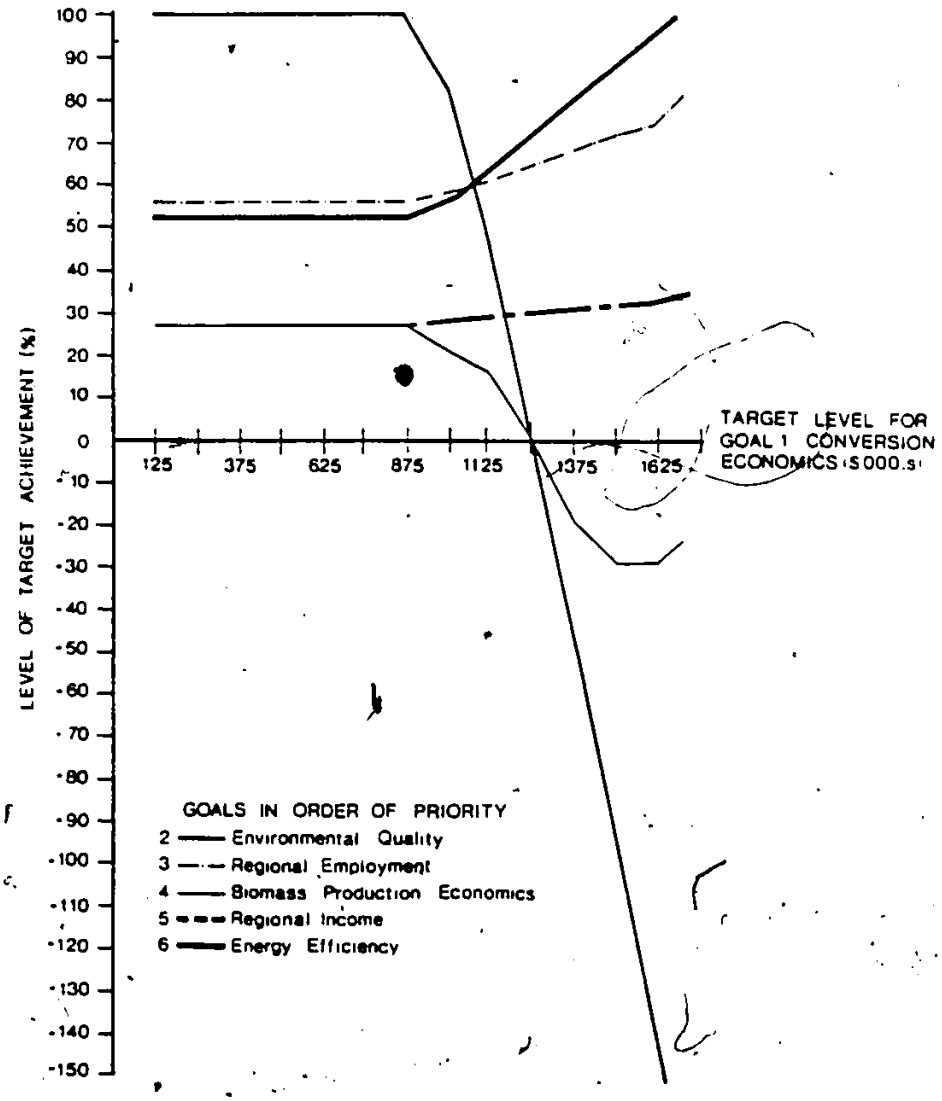


FIGURE 6.8 GOAL RELATIONSHIPS AT ALTERNATIVE TARGET LEVELS FOR CONVERSION ECONOMICS: EXAMPLE 3

retains under the 4K system land in those townships with the highest erosion coefficients for the 35K system, since this minimizes the over-achievement of the environmental quality goal. Land assigned to the 4K system is that in Cornwall township. For this township, returns to biomass production are greater for the 35K system than the 4K system. Thus, when the target level for conversion economics is increased to the maximum attainable level, making it necessary for all land to be assigned to the 35K system, an improved result is obtained with respect to biomass production economics.

Regional employment generation was then placed second to conversion economics. To minimize the deviation from the specified target level for this goal, the model assigned all land to the 35K system, maximizing biomass output. Biomass was allocated to the methanol plant and to co-generation. The quantity of biomass allocated to the methanol plant at all target levels for conversion economics was, however, less than the specified minimum (see Section 5.3.1). This required that methanol be excluded as an end-use option. Consequently, all biomass was assigned to the co-generation facility up until the highest target level, at which 2,365 ODt were allocated to institutional heating. Under these conditions, there is a substantial over-achievement for conversion economics at lower target levels. Moreover, the result cannot be

improved upon for the two highest priority goals, which means that the result is invariant with increases in the target level for conversion economics. Achievement levels for all goals are therefore constant over the entire target range for conversion economics, as illustrated in Figure 6.9.

In a third set of scenarios, regional employment was set at the first priority level and the target was varied over a range from 100,000 to 900,000 worker-hours in equal increments and then to the maximum attainable level of 961,468 worker-hours. As in the previous examples, targets for all other goals were held constant at the levels specified under the base model. Selected results are presented in Figures 6.10, 6.11, 6.12 and 6.13. The patterns exhibit some similarities to the results obtained with respect to changes in the target for energy conversion economics. In each case, however, biomass is assigned initially to the co-generation facility and the institutional heating complex, but then is switched to the methanol plant as the target level on employment generation increases. As a result, the achievement levels for both energy efficiency and energy conversion economics precipitously decline as larger quantities of biomass are allocated to methanol production. The achievement curves for conversion economics corresponding to each of the scenarios illustrated in Figures 6.10, 6.11 and 6.12 are

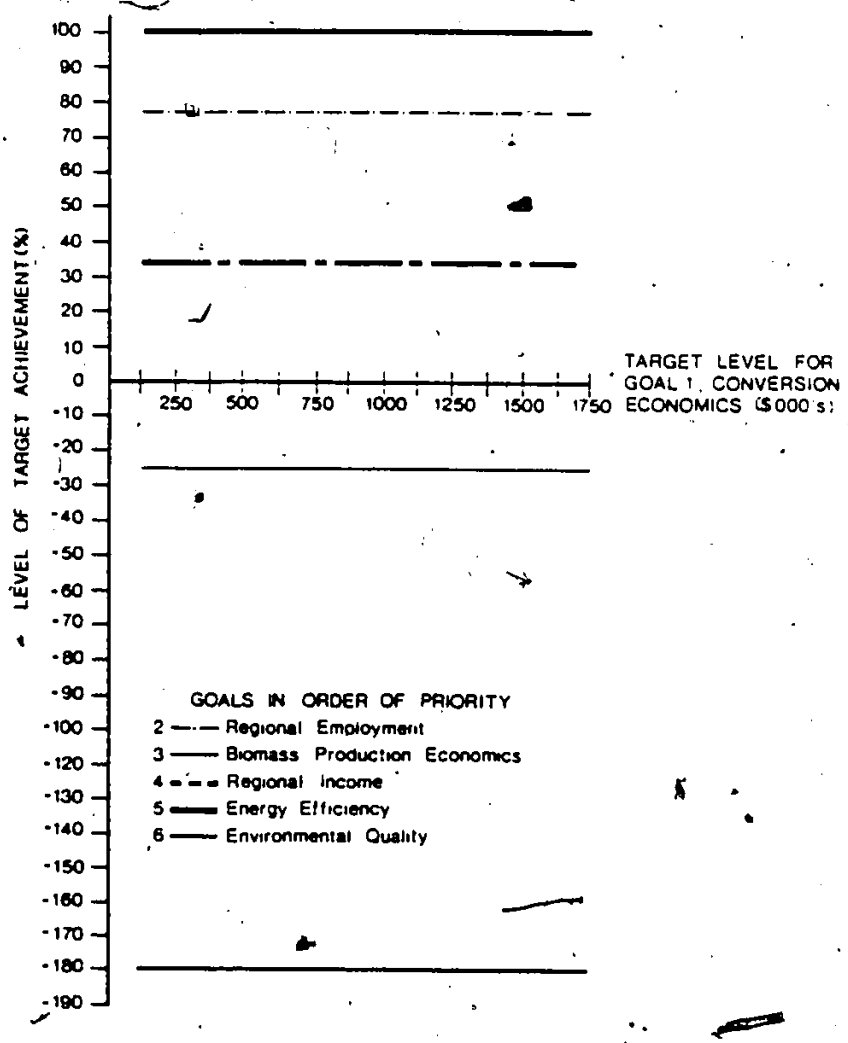


FIGURE 6.9 GOAL RELATIONSHIPS AT ALTERNATIVE TARGET LEVELS FOR CONVERSION ECONOMICS: EXAMPLE 2

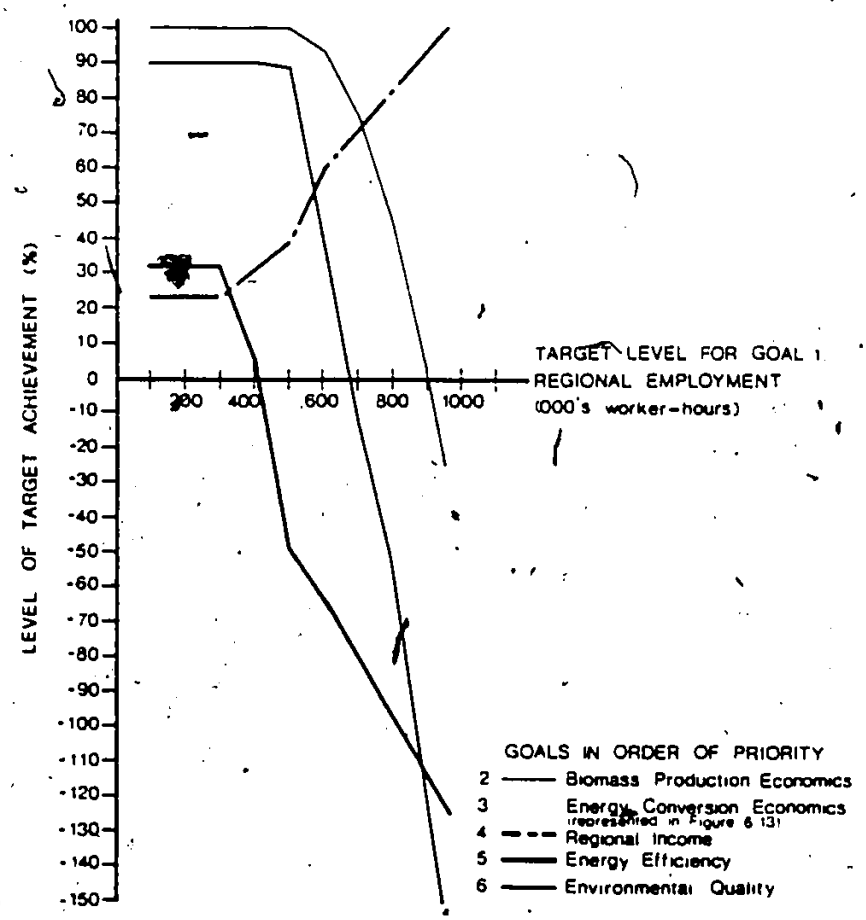


FIGURE 6.10 GOAL RELATIONSHIPS AT ALTERNATIVE TARGET LEVELS FOR REGIONAL EMPLOYMENT EXAMPLE 1

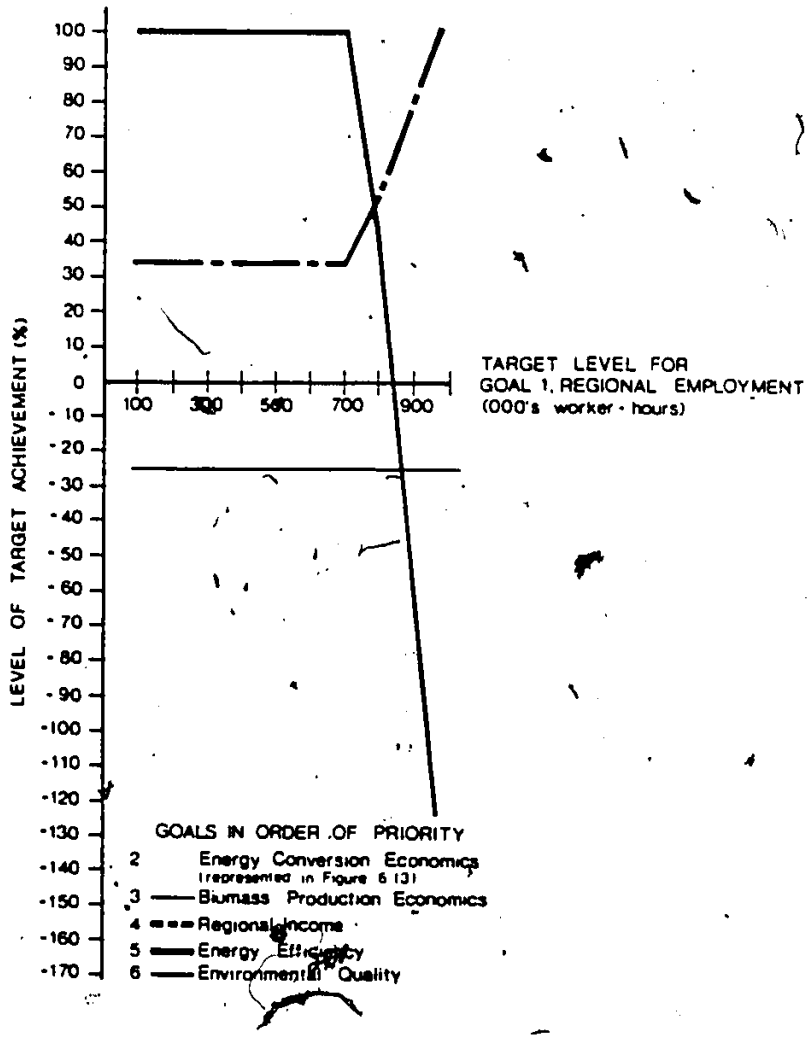


FIGURE 6.11 GOAL RELATIONSHIPS AT ALTERNATIVE TARGET LEVELS FOR REGIONAL EMPLOYMENT. EXAMPLE 2

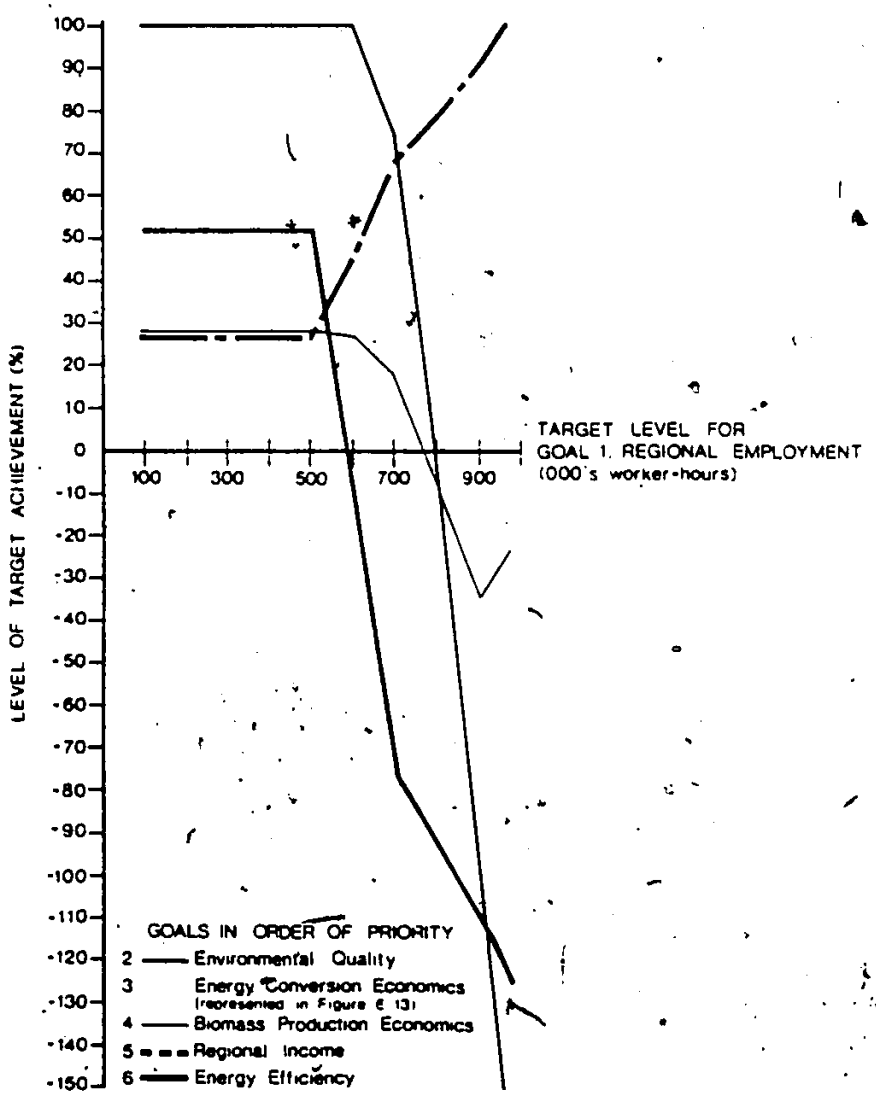


FIGURE 6.12 · GOAL RELATIONSHIPS AT ALTERNATIVE TARGET LEVELS FOR REGIONAL EMPLOYMENT: EXAMPLE 3

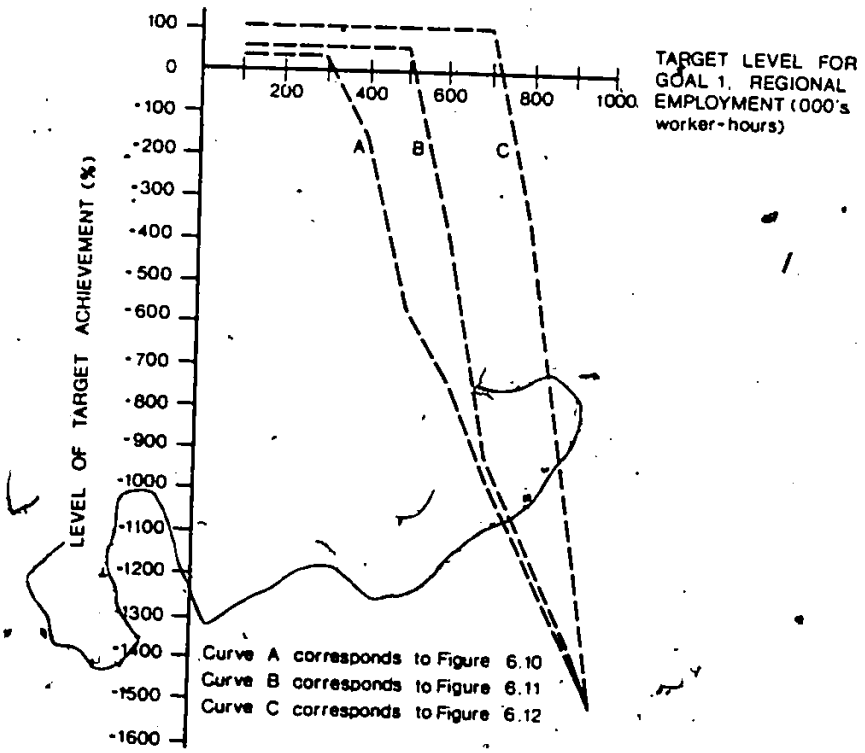


FIGURE 6.13 GOAL ACHIEVEMENT FOR CONVERSION ECONOMICS AT ALTERNATIVE TARGET LEVELS FOR REGIONAL EMPLOYMENT.

represented separately in Figure 6.13, due to the large differences in magnitude.

At the lower target values for regional employment, the quantity of land allocated to the 35K system differs according to the goal ranked at the second priority level. This accounts in part for the fact that the point at which the curves assume non-zero slopes differs between the two figures. For the example illustrated in Figure 6.12, all land is allocated to the 35K system at the outset, with the result that the slopes of the curves for conversion economics, regional income and energy efficiency do not become non-zero until a much higher target level for regional employment is reached. This also results in achievement levels for production economics and environmental quality being constant over the entire range.

Since resource allocations that favour regional employment have been found to also favour regional income generation, trends in goal achievement curves similar to those for regional employment were expected in response to variations in the target level for regional income. The regional income goal was placed at the highest priority level and the target was increased in equal intervals over the range $3,000,000 to $33,000,000 and then to $33,194,073, the maximum attainable level. Results under one goal priority ordering are illustrated in Figure 6.14. As expected, the general trends in the curves are very

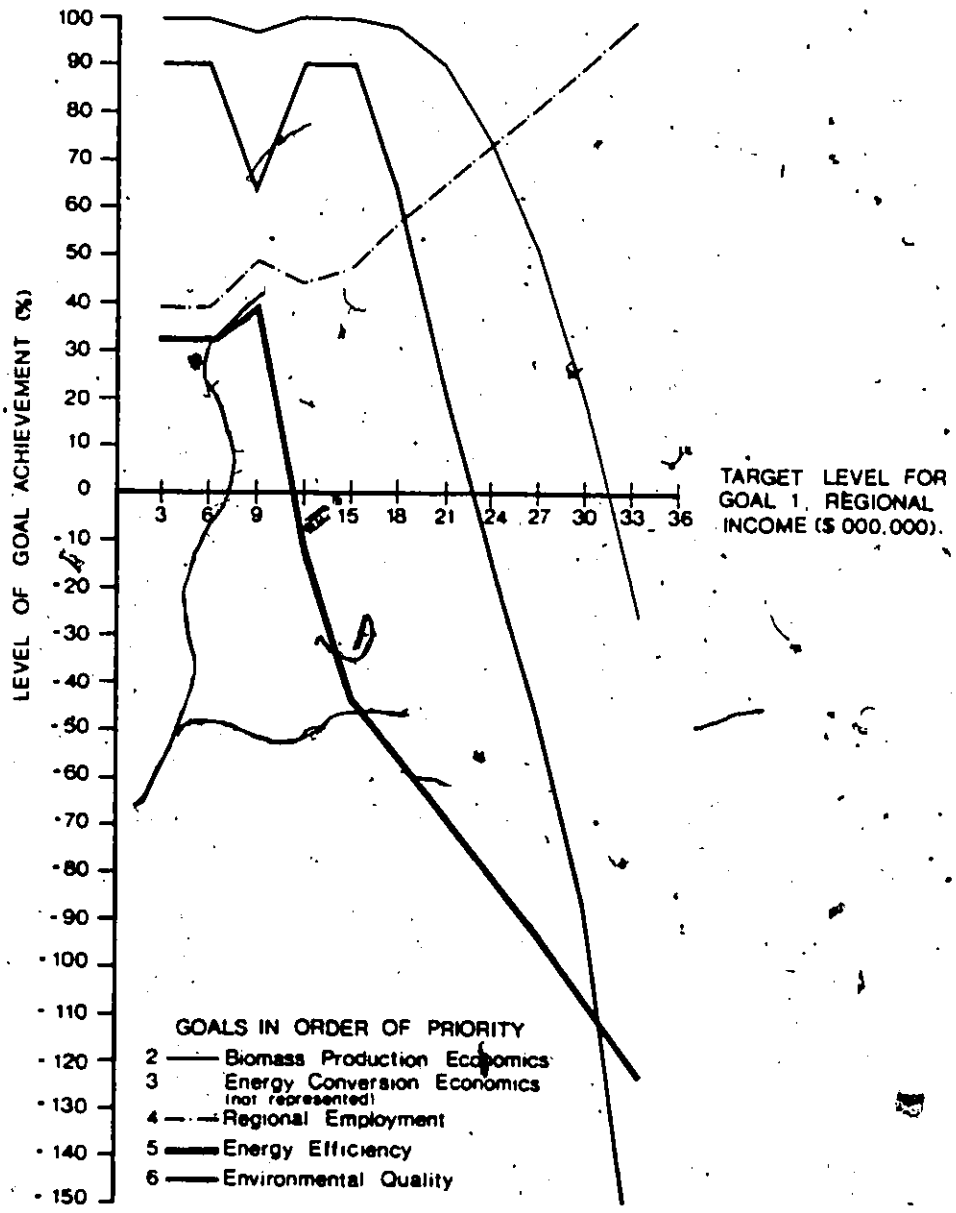


FIGURE 6.14 GOAL RELATIONSHIPS AT ALTERNATIVE TARGET LEVELS FOR, REGIONAL INCOME

similar to those identified as the regional employment target was varied under the same priority ordering (Figure 6.10). The one notable aberration, at a target level of $9,000,000 for regional income, is explained by the fact that at this level methanol had to be excluded as an end-use option, since the initial allocation of biomass fell short of the acceptable minimum. Consequently, greater areas of land were devoted to the 35K plantation at this target level in order to satisfy the target for regional income, with predictable results in terms of the other goals. Further runs under alternative goal priority orderings also revealed similar patterns to those found in response to variations in the target for regional employment. For this reason, they are not illustrated here.

The compatibility of the energy conversion economics goal and the energy efficiency goal suggests that the curves representing achievement levels for other goals would respond similarly to variations in target levels for either economics or energy. This is borne out by the results illustrated in Figure 6.15. As the target level on energy efficiency is varied over the range 500,000 GJ to 5,899,085 GJ, and with this goal set at the highest priority level, curves illustrating the achievement levels for other goals respond in similar ways to those illustrated in Figure 6.7. Aberrations over the range 1,000,000 GJ to 1,500,000 GJ are accounted for by the fact

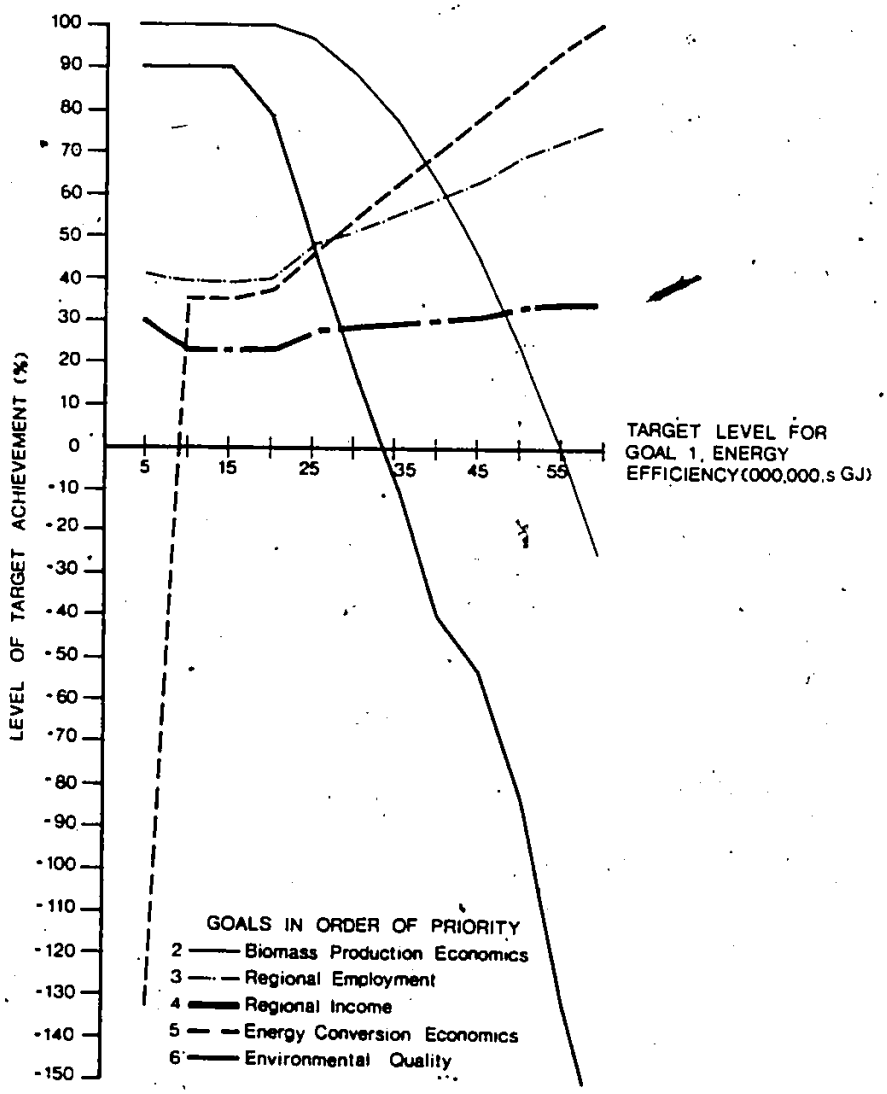


FIGURE 6.15 GOAL RELATIONSHIPS AT ALTERNATIVE TARGET LEVELS FOR ENERGY EFFICIENCY

that methanol was again excluded as an end-use option, all biomass then being allocated to co-generation. Further examples are not illustrated, given the similarity in results to those obtained with variations in the conversion economics target.

The analyses described above have yielded some particularly interesting results. It was observed, for example, that there is a marked increase in the marginal rate of change in the level of target achievement for most goals as the target for production economics closely approaches its maximum. In other scenarios, as the target for the highest ranked goal was gradually increased, relationships between the goals remained constant up until a "threshold" level, after which the relationships changed dramatically (see, for example, Figures 6.7 and 6.10).

Throughout the analysis, distinctive patterns of correspondence between the achievement levels for particular goals emerged, and these relationships are typically consistent with those previously identified. As the level of achievement for the biomass production economics goal declines, for example, so does the achievement level for environmental quality. At the same time, levels of goal achievement for regional income and regional employment generation are likely to increase.

The analysis, therefore, has contributed to an improved understanding of the relationships between the

specified development goals. This information might contribute to the identification of resource development strategies that achieve an acceptable compromise between development priorities. This component of the analysis has also served to highlight the importance of target setting, by demonstrating that individual goal targets may have a significant influence on the manner in which resources are utilized.

6.6 UNCERTAINTIES, DEVELOPMENT CONSTRAINTS AND OTHER ISSUES

The type of resource assessment performed here and the planning process to which it contributes are characterized by uncertainty. In this research, for example, there is uncertainty with respect to desired levels of achievement for the respective goals and in terms of the perceptions regarding the importance of each goal relative to all other goals. By specifying alternative target levels and priority orderings, attempts have been made to address these types of uncertainty in the previous sections.

Uncertainty also exists in the sense that analysts and decision makers are also often confronted by the fact that they have inadequate information on the nature of production relationships, either in the present or for the

future. Information on resource availability may also be incomplete. Additionally, planners and decision makers may lack precise information on institutional constraints and incentives, which may also influence resource management decisions. Assessing the implications of these types of uncertainty was acknowledged in the Introduction to be a question of fundamental importance in resource assessment.

The opportunity is taken in this section to address, within the framework of the resource assessment model, some of these uncertainties associated with the development of forest energy plantations in Eastern Ontario. The approach followed is essentially the same as the procedures used in previous sections, in that model coefficients are re-specified, the model run, and the results compared to those previously obtained. The first section examines the impact of changes in the assumed biomass supply price. Following this, changes are made to the methanol energy coefficient, based on the analysis of Section 5.3.6. Finally, a constraint is added to evaluate the effect of a requirement that a co-generation plant of a specified size be built.

These particular model adjustments respond to pertinent questions that emerged during model formulation and calibration. The examples should be sufficient to illustrate the manner in which the sensitivity of results to changes in any set of coefficients can be assessed in

order to address questions of uncertainty. Results of these analyses provide a reasonable indication of the ways in which solutions respond to re-specification of model coefficients.

6.6.1 Sensitivity to Biomass Supply Prices

Analyses to this point have been based on the assumption that the biomass supply price equals $42.50/ODt. Supply prices have a direct effect on the economics of biomass production and upon energy conversion economics. Modest changes in the assumed biomass supply price were made in order to assess the implications of alternative supply prices, both in terms of the economic efficiency goals and in regard to the other development concerns.

In the first case, the biomass supply price was increased to $45.00/ODt. At this supply price, the 35K system provides higher net returns than the 4K management system over a wider area than previously (see Tables 5.4 and 5.5). Also as a consequence of the higher supply price, the maximum attainable level of economic return to biomass production for the region increases to $2,356,348. This return is provided under the resource allocation pattern illustrated in Figure 6.16. The higher supply price would, of course, make the 4K system economically viable beyond the study area boundaries, but the extended economic

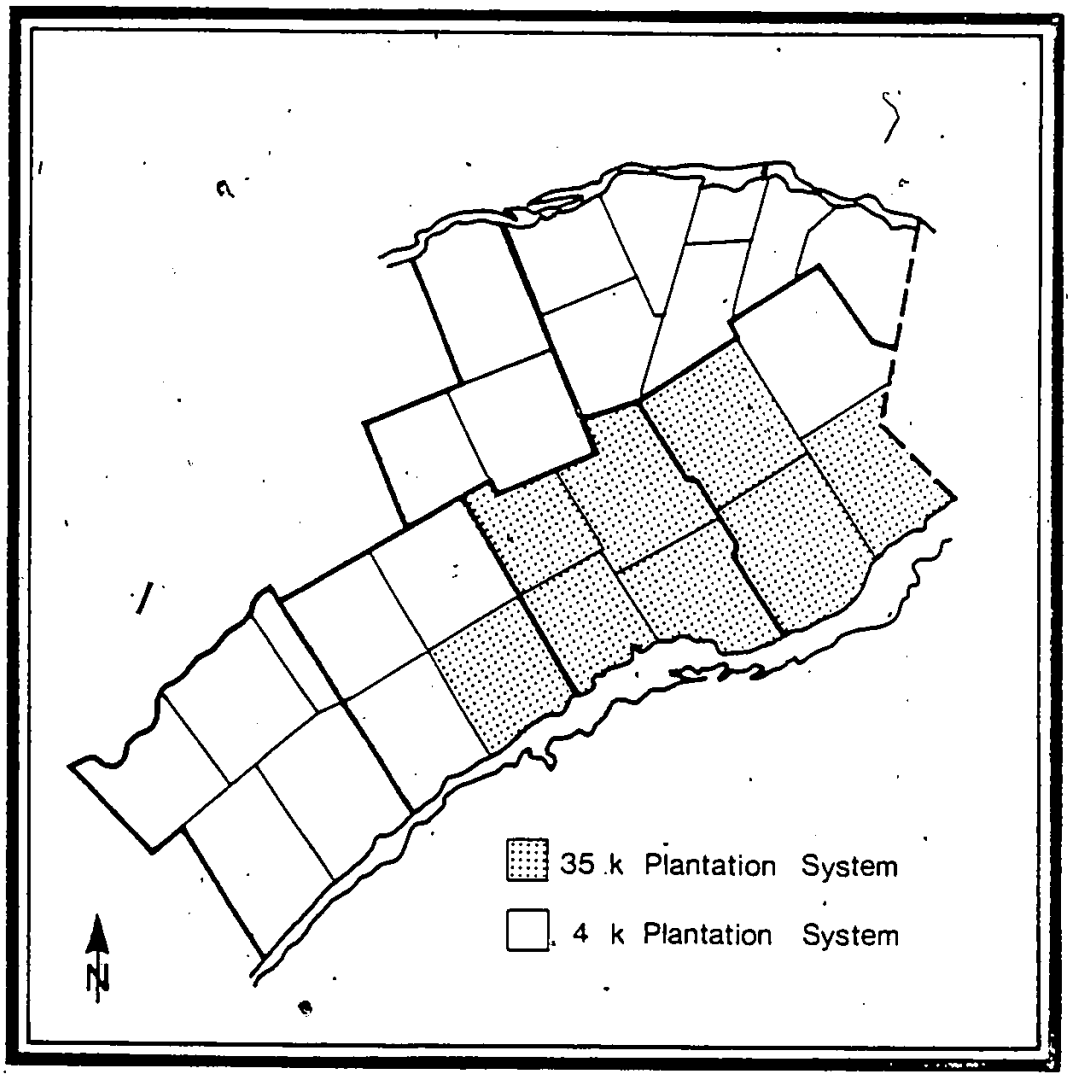


FIGURE 6.16 Land resource allocation pattern with biomass supply price increased $45.00/ODt.

production area is not accounted for here.

An increase in the price of biomass also leads to lower returns to energy conversion processes (see Section 5.3.3). Consequently, the maximum attainable level of economic return to energy conversion in the region declines to $462,319.

Goal conflict analysis was repeated, assuming the higher biomass supply price. Selected results are presented in detail in Appendix E, Table 1. Goal relationships are summarized in Figure 6.17. The results differ from those obtained from the base model in several respects. The maximum attainable level of economic return to biomass production is achieved with a greater area devoted to production under the 35K system than previously. This means that greater quantities of biomass are available to end uses when economic efficiency in biomass production is at the highest priority level (Scenario 1, Table E1). Consequently, improved results are obtained with respect to regional employment and income generation and the energy efficiency goal, in terms of absolute levels of achievement and percentage of goal achievement, as compared to the results reported in Table 6.2. An improved result for conversion economics is also obtained in terms of the percentage of goal achievement (Scenario 1, Table E1), but the absolute level of financial return is less than reported in Table 6.2.

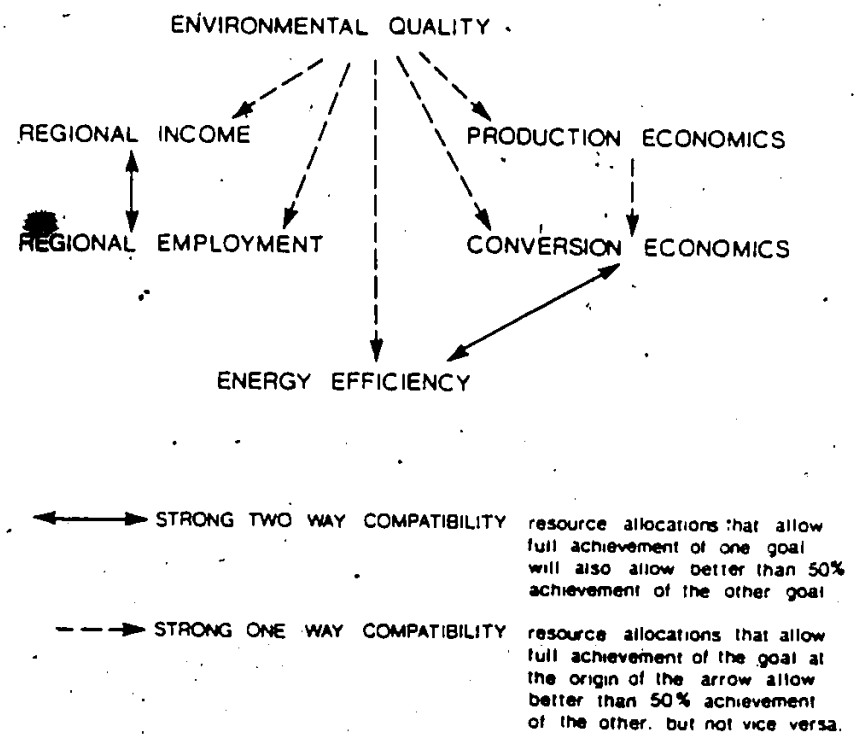


FIGURE 6.17 Goal relationships with biomass supply price increased to $45.00/ODt

Of note also is the fact that the close compatibility between the production economics goal and environmental quality is no longer maintained (see Figure 6.4). This again is because production economics is favoured by a greater area in production under the 35K plantation system, which typically involves higher rates of soil erosion. Factors which improve the economic viability of the 35K system, therefore, are likely to result in greater environmental disruption, relative to circumstances in which the 4K system is adopted over a wider area.

Maximization of regional employment and income generation is again achieved by allocating all biomass to the methanol plant (Scenario 3, Table E1). Because of the higher input prices, the coefficient expressing net financial returns is more negative, which means a larger financial loss to energy conversion. Although all land is assigned to the 35K plantation system, note that total returns to production economics are not negative in this case.

The analysis was repeated, this time assuming a lower biomass supply price of $40.00/ODt. The 35K management system now provides higher economic returns than the 4K system in Cornwall township only, and the maximum attainable level of economic return to production for the region is considerably lower at $962,356. Lower biomass input prices lead to improved net economic returns to

energy conversion (see Section 5.3.3), and the regional maximum is equal to $2,914,039, with all biomass produced (490,344 ODt) assigned to the institutional heating complex (2,365 ODt) and co-generation (487,979 ODt).

Detailed results of goal conflict analysis, with biomass supply price set at $40.00/ODt, are reported in Appendix E, Table 2. The general relationships among goals are the same as those portrayed in Figure 6.4. With production economics set at the first priority level (Scenario 1, Table E2), both the absolute levels and percentage of goal achievement are lower than attained previously for all goals, except environmental quality. For the latter, annual soil erosion is less than the target level, since almost all land in the region is allocated to production under the 4K management system. The conflict between production economics and conversion economics is accentuated, as reflected in the substantial financial deficit for biomass production economics when returns to energy conversion are maximized (Scenario 2, Table E2). The improved coefficients for conversion economics means that the net financial loss when all biomass is allocated to methanol production is less than under the base model (Scenario 3, Table E2).

Model solutions, therefore, vary in three major ways in response to changes in input coefficients that are determined by assumed biomass supply prices. First, the

land resource allocation patterns are affected, in that the spatial range over which alternative plantation management patterns are economically competitive differs according to supply price. Secondly, both of the economic efficiency goals are expressed as functions of biomass supply price, which inevitably means that the maximum attainable values are explicitly determined by the price paid for the biomass. Finally, the degree of conflict between goals differs according to biomass supply price and there are some differences in the nature of goal relationships from those identified under the base model.

6.6.2 An Alternative Scenario for Methanol Production

In Chapter 5, it was acknowledged that the energy efficiency of the methanol facility will depend upon the source of the methane. To this point, analyses have been based on the assumption that the methane is obtained from natural gas, which, according to the energy accounting procedure adopted here, means that methanol production has a negative net energy balance. If the methane was alternatively obtained from a municipal solid waste conversion facility, methanol production would have a positive net energy balance (see Table 5.14). In this section, the implications of the latter are assessed.

Under the assumption that methane is obtained from a

municipal solid waste plant, methanol is the preferred end use in terms of energy efficiency (Table 5.14). Consequently, the maximum possible net energy output from a regional biomass energy system will differ from that of the base model. Maximum possible net energy in fact increases, from 5,899,085 GJ to 27,704,218 GJ.

The nature of goal relationships will also differ under the present assumptions to those obtained for the base model (Figure 6.18). Notably, the previous compatibility between conversion economics and energy efficiency is not maintained, whereas regional employment and income generation and the energy efficiency goals now exhibit compatibility. More detailed results for selected combinations of goal priority orderings are presented in Appendix E, Table 3.

6.6.3 The Question of Plant Size

In the cases of co-generation and methanol production, plant size has been permitted to vary over a wide range. Only in the case of the institutional heating complex has the size of the facility been fixed at a specific level. Conceivably, however, the co-generation and methanol plants might also be restricted to specific output levels.

Plans exist, for example, to replace the natural gas

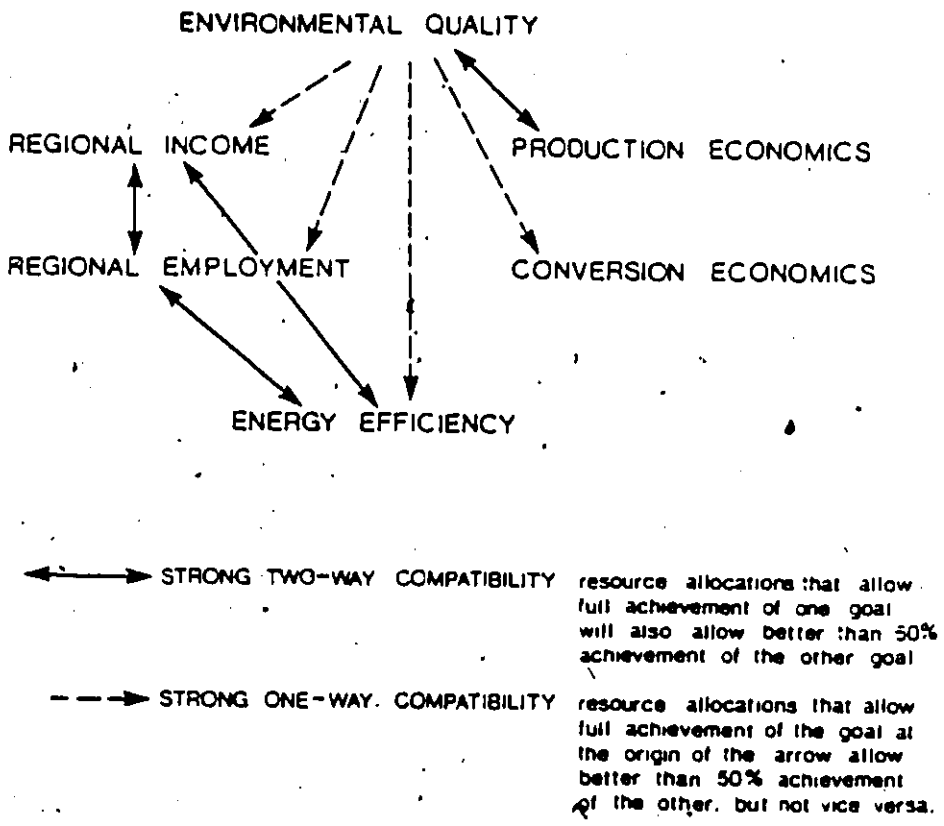


FIGURE 6.18 Goal relationships under the assumption that methane is obtained from a solid waste plant.

plant at the Canada Starch industrial complex in Cardinal, Eastern Ontario, with a wood-fired co-generation facility (Peat, Marwick and Partners, 1981b). In this case, a 9MW plant is required to satisfy the energy demand of the industrial complex. Unless increased energy demand is projected or the opportunity existed to sell excess energy output to the municipality, it would make little sense to build something other than a 9MW plant.

The question then emerges as to what the effect will be if the scale of development for specific end uses is strictly limited. For the purposes of this analysis, the circumstances considered are that a 9MW co-generation facility must be constructed. Biomass produced in the region in excess of that required to fuel the co-generation facility can be used for institutional heating or methanol production, where the size restrictions on these are the same as those for the base model. The possibility of additional co-generation plants is not considered.

The first observation is that the maximum attainment levels for several of the goals differ from those of the base model. Maximum goal levels are reported in Table 6.4. Comparing these to the levels reported for the base model, reduced attainment levels are found for conversion economics, regional employment, regional income generation and total energy. The other goals are unaffected.

Further analysis was undertaken in order to

TABLE 6.4

GOAL TARGET LEVELS WITH THE CO-GENERATION FACILITY CONSTRAINED TO A 9MW OUTPUT LEVEL

Goal	Target Level
Production Economics ($)	1,544,052
Conversion Economics ($)	338,543
Regional Employment (hours)	905,580
Regional Income ($)	27,768,062
Energy Efficiency (GJ)	1,509,606

establish the effects in terms of goal conflicts. Selected results are presented in detail in Appendix E, Table 4, while Figure 6.19 presents a summary of the goal relationships identified. The only notable difference from the base model is that production economics and conversion economics exhibit compatibility. This is because returns to energy conversion are maximized by developing only the co-generation plant and the institutional heating complex. Since the combined biomass input requirement for these is quite small (relative to the base model), biomass is produced primarily under the 4K system.

6.7 THE RESOURCE ASSESSMENT ANALYSIS IN REVIEW

Application of a goal programming system in an analysis of the hybrid poplar project has served the purpose of establishing, within an applied context, the suitability of the method for resource assessment. This has helped to resolve questions relating to the methodology, but the value of the information generated with respect to forest energy developments in Eastern Ontario should not be underestimated. The analysis described above offers a sufficiently comprehensive base for drawing important conclusions in relation to this resource development project, and stands alone as a significant contribution of the research. This section draws together the major

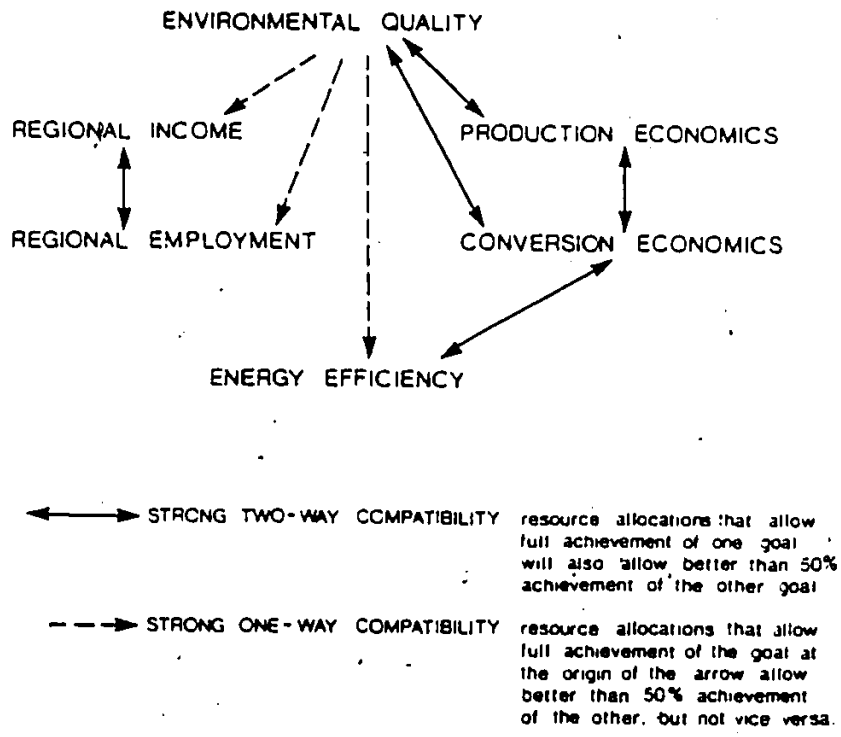


FIGURE 6.19 Goal relationships with the co-generation facility constrained to a 9 MW output level.

findings in terms of forest energy projects in Eastern Ontario.

First, it is apparent that resources could be allocated to biomass production and energy conversion such that positive financial balances are achieved in both production and conversion. Resources can also be allocated such that positive energy balances are achieved. Under certain resource development strategies, over $33,000,000 in additional regional income could be generated and close to 500 new jobs created. Opportunities also exist to establish a hybrid poplar-based energy system without necessarily causing substantial increases in soil erosion rates.

All of this cannot be achieved simultaneously, however. Conflicts exist between the various goals and resource allocations which imply favourable results in terms of one development goal may mean relatively poor achievement levels with respect to other goals. Based on the various scenarios investigated, three groups of goals can be identified. Goals within these groups are generally mutually compatible, but conflicts were found to exist between these groups of goals. The groups are as follows:

Group 1: Production economics and environmental quality.

Group 2: Conversion economics and energy efficiency.

Group 3: Regional income generation and regional employment generation.

An explanation of these goal relationships lies in the specific characteristics of the various resource allocation alternatives (ie., plantation management systems and end-use facilities). If poplar production is to be an economically viable enterprise, for example, plantations for the most part must be established under the 4K management system. The 35K system is economically competitive only in areas proximate to the market. Because of the lower annual productivity of the 4K system, a resource allocation pattern that favours production economics necessarily means that the scale of energy conversion operations will be considerably smaller than if the higher productivity 35K system were adopted throughout the region. This also has important implications for net energy output and rates of regional income and employment generation, both because of the smaller-scale energy conversion operations and because the 35K system is more labour and capital intensive.

More extensive development of the 35K system is clearly desirable from several perspectives. If plantation development is left to private landowners, however, this implies that one of two things may be necessary in order to encourage development under this management system. One alternative is government subsidization of plantation

operations. The benefits in terms of regional economic development might be considered to be reasonable justification for such involvement. The 35K plantation system will also be competitive over a wider area if biomass supply price increases. This may, however, jeopardize the economic viability of energy conversion operations.

Financial viability in energy conversion requires that the methanol plant be excluded as an end-use option and that the biomass energy system be centred around institutional heating and electricity and steam co-generation. Positive net energy balances will also be assured. This, however, implies sacrifices in terms of both regional employment and regional income generation, relative to a situation in which a methanol facility was developed. Conversely, maximization of regional income and employment generation, through the development of a methanol plant, would result in a substantial financial loss. Depending on the source of the methane feedstock, methanol production may also be a net energy loser.

Government subsidization might be advocated, again in the interests of regional employment and income generation. Methanol production might also be viewed as an important contribution towards reducing dependence on imported oil. A subsidy of over $25,000,000 would be necessary to allow the methanol plant to break-even;

according to the assumptions of the base model. Approximately 100 more jobs would be created by developing a methanol plant rather than a combination of institutional heating and co-generation, at a cost of almost $250,000 per additional job created. Clearly, the cost of greater energy self-sufficiency and job creation, within this context, is considerable.

Further analysis revealed that as expectations with respect to achievement levels for specific goals are adjusted, changing patterns emerge in terms of the extent, and in some cases the nature, of goal conflicts. Ultimately, it is up to the decision makers to arrive at resource development strategies that represent an acceptable compromise. Sensitivity analysis in terms of the target levels provides information that may lead to an improved understanding of the implicattions of certain compromise development strategies. Specifically, as expectations with respect to one goal are adjusted, the analysis serves to identify the costs in terms of the other development priorities.

The need to address uncertainties with respect to production relationships, resource constraints and institutional factors has been repeatedly acknowledged, and is considered to be an important component of resource assessment. In Section 6.6, several adjustments to the model for Eastern Ontario are described. Relative to the

total amount of sensitivity analysis that might be conducted in response to the various uncertainties, that actually conducted here is limited. The analysis does, however, provide useful examples of the types of uncertainties that can be addressed using the programming model. At the same time, this analysis provides at least some indication of the ways in which this particular model will respond to changes in model coefficients.

Additionally, the analysis of uncertainties responds to important questions that emerged during model formulation and calibration. The price at which biomass will be sold by producers, for example, is unknown beyond the fact that price will probably be between $35.00 and $50.00 per oven dried tonne. The sensitivity analysis clearly indicates that biomass price could have an important effect on the manner in which a forest energy system might develop. Price will determine economic viability of the alternative management systems and consequently regional production levels. This will in turn determine the scale at which energy conversion facilities can be developed. By influencing both the regional combination of management systems adopted and the scale of energy conversion operations, biomass price will also influence regional employment and income generation, energy efficiency and rates of soil erosion.

The source of methane for the methanol facility

raises questions beyond those of energy accounting procedures. Construction of a municipal solid waste plant might be seen as a further step towards the establishment of a renewable energy system for the region, and perhaps beyond. In the absence of suitable information, only the energy implications could be investigated here. Concurrent development of a solid waste conversion facility, though, may also have important implications for other goals, such as regional employment and income generation.

Finally, the flexibility in scale of development of energy conversion facilities that is assumed throughout much of the analysis may not in fact be present when it comes to the actual development of a regional biomass energy system. For end uses other than institutional heating, fixed demand sources are a possibility. Proposed development of a wood-based energy system for the Canada Starch plant is a case in point. The analysis described in Section 6.6.3 serves to illustrate some of the possible implications of this type of development scenario.

From a methodological perspective, these analyses have served to confirm that goal programming is a method that facilitates investigation of the implications of uncertainties, without encountering major technical difficulties. Moreover, the analysis demonstrates that the modelling system offers flexibility in terms of the types of questions that can be addressed. From an applied

perspective, this component of the research provides information on topical questions relating to the development of a forest energy system in Ontario. The analysis also provides a reasonable indication of the sensitivity of this particular goal programming model to changes that arise from uncertainties in its representation and specification.

6.8 SUMMARY

The analysis described in this chapter has primarily been devoted to determining the extent to which various goals relating to the development of a biomass energy system in eastern Ontario can be satisfied, under alternative priority orderings, and identifying the nature and extent of goal conflicts. Analyses have also been directed at identifying the sensitivity of model solutions to input information about which there is some uncertainty. This is consistent with the objectives of the research, since these questions collectively constitute what has been referred to here as resource assessment.

Within the broad terms of reference of this research, the application described above serves two important purposes. First, the analytical exercise provides an applied context within which to evaluate a specific methodology, goal programming, for resource assessment.

Secondly, information has been generated on the possible regional implications of the establishment of a forest energy system, and this could be of value in identifying resource development strategies for the future. The concluding chapter presents a final evaluation of goal programming as a method for resource assessment and some further thoughts on forest energy developments.

CHAPTER 7

CONCLUSIONS

7.1 RETROSPECTIVE ON THE METHOD

This research has primarily been concerned with the identification, development and implementation of methods for the purpose of providing information that will assist in making reasonable decisions with respect to the utilization of natural resources. The type of information sought was defined by four specific questions. The first referred to the ability to satisfy development goals, given available resources and taking explicitly into account the relative preferences held for the achievement of stated development goals. It was recognized that answers to this question would be directly influenced by the assumptions employed with respect to production relationships, resource limitations and institutional constraints, about which there is typically considerable uncertainty. The second question, therefore, referred to the implications of employing alternative assumptions, in response to these uncertainties.

There may also be uncertainty with respect to the relative importance assigned by decision makers, and other interested parties, to the achievement of the specified development goals. The implications of considering alternative priority orderings of development goals constituted the third research question. A fourth, and closely related question, concerned the nature and extent of conflicts between the stated development goals. Analysis directed at addressing these four questions was referred to as resource assessment.

A major component of the research was methodological, in that it involved the search for suitable methods by which to undertake resource assessment analysis. To effectively respond to the four research questions required a method with special characteristics. The method, for example, must have the capability to generate resource allocation patterns that best satisfy the stated criteria. That is, resource assessment analysis is not concerned with the evaluation of a set of pre-specified alternatives. In addition, the method must have the capability to account for multiple, conflicting goals, which may be expressed in disparate metrics.

Several methods were considered, each of which was eventually rejected for resource assessment analysis upon recognition that they failed to satisfy at least one of the requirements noted above. Multiobjective goal programming

did, however, appear to have the necessary capabilities for resource assessment. The formulation and application of a goal programming model in an assessment of the Eastern Ontario forest energy project provided the opportunity to further establish the suitability of the method for resource assessment.

The successful application of a goal programming model to the Eastern Ontario resource development project represents an important contribution of the research in a methodological sense. The contribution lies in the fact that this research has demonstrated that it is possible to systematically and rigorously respond to questions that are of considerable importance with respect to the management of natural resources. In particular, this research has shown that it is possible to assess options in resource use with respect to several, potentially incompatible, goals.

The questions associated with resource assessment analysis have not traditionally been the subject of mainstream scientific inquiry. Consideration of potential conflicts between development goals, for example, is often viewed as being entirely a political matter. The research described here has clearly shown that there are scientific procedures available by which to assess the potential to achieve specified development goals. At the same time, the nature and extent of conflicts between the goals can be precisely identified. Moreover, the goal programming model

provides a useful framework within which to evaluate the many uncertainties that may be associated with specific resource development proposals. Hence, the potential for forest energy plantations to "contribute to the Eastern region" can be assessed precisely and systematically, in terms of the ability to achieve specific goals.

The analysis is not intended to provide an "optimal" solution in terms of a resource development strategy. Instead, the research provides answers to certain fundamental questions relating to development options and trade-offs between goals and, in so doing, supplies vital information to decision makers. Final recommendations with respect to the resource development proposal must emerge from close consultation between analysts and decision makers. By providing quantitative measures of the extent to which goals can be satisfied and with the capability to assess alternative resource development strategies in relation to multiple goals, the potential contribution of a goal programming-based resource assessment system to resource management decisions is clearly substantial.

The four questions which collectively define the nature of resource assessment analysis are relevant to a wide variety of resource planning contexts. The method, therefore, should prove to have value for assessing a broad range of resource development issues. The generality of both the conceptual and analytical framework suggests

considerable potential for more extensive application.

Several observations on the use of goal programming for resource assessment analysis deserve further consideration, however. First, there is some concern over the ability to effectively specify within the framework more abstract goals that sometimes arise in development planning. Common examples are those relating to community relations and environmental aesthetics. For analysts, these have proved virtually impossible to express quantitatively. When such concerns cannot be expressed by numerical measures, they must be excluded from a goal programming framework. This, of course, is not unique to goal programming, but at the same time, the necessary omission of factors that may be of importance in relation to some resource development proposals is a source of concern.

In a somewhat similar vein, it may not always be possible to easily specify some measures of goal achievement in the programming framework. Those used here proved relatively easy to define within the operational model. Conceivably, some measures of goal achievement may prove to be difficult to specify in an operational sense.

Also worthy of mention is the fact that development and implementation of a goal programming system may impose considerable demands in terms of time and money. Even for the relatively small model developed here, data collection and model calibration proved to be an extremely time

consuming process. Once again, this is not unique to goal programming, but potential users must be made aware that resource needs for model development, in terms of both time and money, can be considerable.

A further observation relates to the desirability of working closely with decision makers. This was afforded to some extent in the application described here, through regular contact with members of the Ontario Tree Improvement and Forest Biomass Institute (OTIFBI) of the Ontario Ministry of Natural Resources. Contact with a broader range of people involved would have been fruitful.

The value of such contact lies in the ability to clearly identify the concerns of those who will be involved in making the final decisions. At the same time, the adoption of a goal programming model may encourage decision makers to more precisely articulate target levels and relative preferences for the achievement of the respective goals. This contact should be initiated during model formulation and continue throughout the investigation. Often it may prove useful to confront decision makers with model results and solicit opinions with respect to further types of analysis. A strong recommendation is made, therefore, for regular consultations between analysts and decision makers.

In addition to the contribution made in demonstrating the ability to perform resource assessments

in a rigorous and systematic manner, the research makes a further contribution by way of the extensive review of methods. All too frequently, research methods have been applied to address questions for which they are unsuited. Methodological reviews such as that presented in Chapters 3 and 4 are essential in clarifying the suitability of methods for specific purposes. The inherent limitations of the various methods are indicated, but upon close scrutiny they are rejected for resource assessment primarily because they are not suited to this type of analysis. Although cost-benefit analysis may, for example, be inappropriate for resource assessment, it may nevertheless be suited to other forms of analysis. Similarly, although goal programming may be useful for resource assessment, there are many questions relevant to resource management decision making for which it may not be appropriate.

Apart from identifying the suitability of particular methods for resource assessment, an important conclusion to emerge from this review is that methods cannot be evaluated in a contextual vacuum. All methods have inherent limitations, but before these are considered, the suitability of a method for a particular form of analysis must be firmly established.

The research, therefore, has made significant contributions in a methodological sense, most notably by demonstrating the ability to systematically and rigorously

address important questions relating to resource development proposals. Goal programming models are potentially a useful aid to decision making and should contribute to better informed decisions regarding the use of natural resources. Through the application of a goal programming model to the Eastern Ontario forest energy project, this research has also made a valuable contribution in an applied sense. The major findings with respect to this resource development proposal conclude this thesis.

7.2 PROSPECTS FOR FOREST ENERGY PLANTATIONS IN ONTARIO

Although the development of forest energy plantations in Eastern Ontario has been the subject of considerable research, investigations had previously been directed almost exclusively to the biotechnological aspects of a biomass energy system. This previous research clearly indicates that appropriate technology is already available for the development of forest energy plantations and the conversion of forest biomass to useable energy.

At the same time, there were vague expectations amongst those involved that forest energy plantations would make important contributions to the region, through the development of underutilized land resources, the provision of jobs, the generation of regional income, and the

production of energy for local markets and perhaps beyond. These potential contributions were an important incentive to the continuing research on a forest energy system. An essential prerequisite to large-scale development of forest energy plantations, however, was that these general expectations with respect to regional development effects be substantiated.

The major development concerns that were identified related to economic efficiency in biomass production and energy conversion, regional employment and income generation, net energy gains, and environmental quality. The formulation and calibration of the goal programming model led to precise expressions of these development concerns and quantitative statements of production relationships and resource constraints. The model in itself, therefore, provides a detailed perspective on the socio-economic and environmental aspects of plantation forest developments in Eastern Ontario.

Implementation of the goal programming model revealed that forest energy developments may, in fact, be economically viable and that such developments may contribute to the region in terms of employment, income generation, and energy production. The results also revealed, however, that not all of the development goals are mutually compatible. Conflicts were found to exist between the specified goals and this suggests that caution

must be exercised in identifying strategies for resource development. Certain strategies may lead to significant gains in terms of some goals, but at great expense in terms of other development concerns.

The analysis, therefore, provides information that may be of considerable value in planning for the large-scale development of forest energy plantations in Eastern Ontario. A basis now exists for establishing the extent to which a forest energy system may actually contribute to regional improvement, under alternative resource development strategies. Additionally, the research has facilitated the identification of incompatibilities between development goals. Extensive sensitivity analysis provided further useful information on the implications of uncertainty with respect to development priorities, targets, production relationships and resource constraints. The research has therefore responded in useful ways to a virtual absence of information on the possible regional consequences of forest energy developments in Eastern Ontario. The information provided may prove to be of value in identifying appropriate resource development alternatives for a forest energy system in Eastern Ontario.

The potential contribution to the Eastern region that has been demonstrated by this research suggests that the development of forest energy projects should be actively pursued in this province. In addition to the

various regional concerns that have been directly addressed in this research, potential benefits can perhaps also be reaped from enhancing the nation's indigenous energy supplies. Even though interest in alternative energy forms has waned somewhat over the last two years, with world oil prices falling rapidly, many analysts view this as a short-term trend. An important opportunity exists to plan for the future, by further developing domestic, renewable energy supply sources. The current period of relative energy abundance should not lead to complacency with respect to the further development of alternative energy resources.

Forest energy plantations may also represent one appropriate response to energy supply problems in the developing world. Forest depletion has led to a severe fuelwood shortage in many Third World countries, with attendant social and economic problems. Additionally, deforestation has had detrimental environmental impacts. The "fuelwood crisis" is perceived by some to be the most serious energy supply problem being confronted in the world today.

Plantation forests have the potential to become an important component of energy programs throughout the developing world. The establishment of energy forests could make a significant contribution to overcoming problems associated with deforestation, while providing a domestic

and renewable source of energy. At the same time, jobs might be provided for the rural poor. Presently, however, these are only general expectations as to the possible benefits of establishing energy plantations in developing countries, just as previously there were general expectations that forest energy projects would contribute to regional improvement in Eastern Ontario. Effective planning for forest energy developments in Third World countries demands that these expectations be substantiated, as there was a need for such corroboration in the case of Eastern Ontario. The severity and urgency of resource supply problems in the developing nations clearly demands effective resource management, and this in turn requires appropriate information.

The generality of the conceptual and analytical framework developed in this research has previously been noted. The framework is sufficiently adaptable that it should have utility for a wide range of resource development contexts. This research may, therefore, offer a useful starting point for an analysis of the social, environmental and economic consequences of forest energy developments, and other resource issues, confronting the Third World nations.

BIBLIOGRAPHY

Ackoff, R., 1977, "Optimization + Objectivity = Opt Out", European Journal of Operational Research, 1(1), pp. 1-7.

Acres Shawnigan Ltd., 1979, Hearst Wood Waste Energy Study, Summary Report. Toronto: Acres Shawnigan Ltd.

Anderson, H., Papadopol, C. and Zsuffa, L., 1983, "Wood Energy Plantations in Temperate Climates", Forest Ecology and Management, 6(3), pp. 281-306

Anderson, H. and Zsuffa, L., 1983a, Hybrid Poplar Plantations in Ontario. In ENERGO '83, proceedings of the conference held in Toronto, Ontario, March 6-9. Toronto: Ontario Ministry of Natural Resources. pp. 134-145.

Anderson, H. and Zsuffa, L., 1983b, Personal communication. Ontario Ministry of Natural Resources, Ontario Tree Improvement and Forest Biomass Institute.

Arnold, G. and Bennett, D., 1975, The Problem of Finding an Optimal Solution. In G. Dalton (ed.), Study of Agricultural Systems. London: Applied Science Publishers. pp. 129-173.

Ash, M., Knoblock, P. and Peters, N., 1980, Energy Analysis of Energy from the Forest Options. Ottawa: Canadian Forestry Service, Environment Canada, ENFOR Report P-59.

Barkley, B., Evers, R. and Raitanen, W., 1983, Soils: The Forest Foundation. In Ontario Ministry of Natural Resources, New Forests in Eastern Ontario: Hybrid Poplar. Toronto: Ontario Ministry of Natural Resources, Science and Technology Series, Volume 1. pp. 63-82.

Bartlett, E., Bottoms, K. and Pope, R., 1976, GOAL: Multiple Objective Programming. Colorado: Colorado State University, Range Science Department, Range Science Series No. 21.

Beattie, K., Bond, W. and Manning, E., 1981, The Agricultural Use of Marginal Lands: A Review and Bibliography. Ottawa: Lands Directorate, Environment Canada, Working Paper 13.

Belenson, S. and Kapur, K., 1973, "An Algorithm for Solving Multicriterion Linear Programming Problems with Examples", Operations Research Quarterly, 24(1), pp. 366-375.

Bente, P (ed.), 1981, The Bio-Energy Directory. Washington: The Bio-Energy Council.

Blair, P., 1979, Multiobjective Regional Energy Planning. Boston: Martinus Nijhoff.

Blankenhorn, P. et al., 1978, Evaluation Procedure for Consideration of Forest Biomass as a Fuel Source for a 100 Megawatt Electric Generating Facility. University Park: College of Agriculture, Pennsylvania State University, Bulletin 820.

Bliss, C. and Blake, D., 1977, Silvicultural Biomass Farms, Volume V: Conversion Processes and Costs. Virginia: MITRE Corporation.

Bowersox, T. and Ward, W., 1976, "Economic Analysis of a Short Rotation Fibre Production System for Hybrid Poplar", Journal of Forestry, 74(11), pp. 750-753.

Brill, E., 1979, "The Use of Optimization Models in Public-Sector Planning", Management Science, 25(5), pp. 413-422.

Brill, E., Chang, S. and Hopkins, L., 1982, "Modeling to Generate Alternatives: The HSJ Approach and an Illustration Using A Problem in Land Use Planning", Management Science, 28(3), pp. 221-235.

Brooks, S., 1958, "A Discussion of Random Methods for Seeking Maxima", Operations Research, 6(2), pp. 244-251.

Brown, C., 1976, "Forests as Energy Sources in the Year 2000: What Man Can Imagine, Man Can Do", Journal of Forestry, 74(1), pp. 7-12.

Brown, D., McKay, G. and Chapman, L., 1980, The Climate of Southern Ontario - Climatological Studies No. 5. Toronto: Atmospheric Environment Service, Environment Canada.

Bullard, C. and Herendeen, R., 1975, "The Energy Cost of Goods and Services", Energy Policy, 1(4), pp. 268-277.

Canada, Department of the Environment, 1982, The Energy Brief: Comments on Alternative Energy Sources. Ottawa: Corporate Planning Group, Department of the Environment.

Canada, House of Commons, 1981, Energy Alternatives. Ottawa: A report by the Special Committee on Alternative Energy and Oil Substitution.

Chang, S., Brill, E. and Hopkins, L., 1982a, "Use of Mathematical Models to Generate Alternative Solutions to Water Resources Planning Problems", Water Resources Research, 18(1), pp. 58-64.

Chang, S., Brill, E. and Hopkins, L., 1982b, "Efficient Random Generation of Feasible Solutions: A Land Use Example", Journal of Regional Science, 22(3), pp. 303-314.

Chapman, G., Smit, B. and Smith, W., 1984, "Flexibility and Criticality in Resource Use Assessment", Geographical Analysis, 16(1), pp. 52-64.

Charnes, A., Haynes, K., Hazleton, J. and Ryan, M., 1977, "A Hierarchical Goal-Programming Approach to Environmental Land Use Management", Geographical Analysis, 7(2), pp. 121-130.

Chatterji, M., 1981, Energy and Environment in the Developing Countries: An Overall Perspective and Plans for Action. In M. Chatterji (ed.), Energy and Environment in the Developing Countries. New York: John Wiley and Sons Ltd. pp. 3-25.

Cheung, H. and Auger, J., 1976, "Linear Programming and Land Use Allocation: Suboptimal Solutions and Policy", Socio-Economic Planning Sciences, 10(1), pp. 43-45.

Church, R. and Huber, D., 1979, On Determining Many Close to Optimal Configurations for Single and Multiple Objective Location Problems. Knoxville: Department of Engineering, University of Tennessee, Research Series No. 34.

Clawson, M. and Knetsch, J., 1966, Economics of Outdoor Recreation. Baltimore: John Hopkins Press.

Cocklin, C., Lonergan, S. and Clark, D., 1985, "Forest Energy Plantations: An International Perspective", Geoforum, forthcoming.

Cockshutt, P., 1980, Energy Alternatives: The Future. In P. Harrison, (ed.), Canada: Energy Futures. Ottawa: Department of Geography, University of Ottawa, Research Notes No. 28. pp. 23-34.

Coelho, J. and Williams, H., 1978, "On the Design of Land Use Plans Through Locational Surplus Maximization", Papers, Regional Science Association, 40, pp. 71-85.

Cohon, J. and Marks, D., 1973, "Multiobjective Screening Models and Water Resources Investment", Water Resources Research, 9(4), pp. 826-836.

Cohon, J. and Marks, D., 1975, "A Review and Evaluation of Multiobjective Programming Techniques", Water Resources Research, 11(2), pp. 208-220.

Cohon, J. et al:, 1980, "Application of a Multi-Objective Facility Location Model to Power Plant Siting in a Six State Region of the U.S.", Computer and Operations Research, 7, pp. 107-123.

Coleman, D., 1984, Personal communication. Lands Directorate, Ontario Region, Environment Canada.

Conservation Foundation, 1982, State of the Environment 1982. Washington: The Conservation Foundation.

Cortes, A., 1981, A Multiobjective Model for Analysis and Planning of an Agricultural Area. Paper presented to the European Congress of the Regional Science Association, Barcelona, August 25-28.

Courtney, J., Klastorin, T. and Ruefli, T., 1972, "A Goal Programming Approach to Urban Suburban Location Preferences", Management Science, 18(6), pp. B258-B268.

Craddock, W., 1970, Interregional Competition in Canadian Cereal Production. Ottawa: Economic Council of Canada.

Cumberland, J., 1966, "A Regional Inter-industry Model for Analysis of Development Objectives", Papers, Regional Science Association, 17, pp. 65-94.

Daly, H., 1968, "On Economics as a Life Science", Journal of Political Economy, 76(3), pp. 392-406.

Dane, C., Meador, N. and White, J., 1977, "Goal Programming in Land Use Planning", Journal of Forestry, 75(6), pp. 325-329.

Dean, G., Bath, D. and Olayide, S., 1969, "Computer Program for Maximizing Income Above Feed Cost from Dairy Cattle", Journal of Dairy Science, 52(7), pp. 1008-1016.

Dick Consulting Services Ltd., 1981a, Investigation to Substitute Biomass for Heating Four Institutional and Public Buildings. Toronto: Ontario Ministry of Natural Resources and Ontario Ministry of Energy.

Dick Consulting Services, Ltd., 1981b, Wood Burning System for Grenville Christian College, Phase II. Toronto: Ontario Ministry of Energy.

Drysdale, D., Morgan, D. and Zsuffa, L., 1983, "Energy Plantations: The Present Situation and Plans for 1983-1988". In P. Nilsson and L. Zsuffa (eds.), Short Rotation Forest Biomass - Production Technology and Mechanization. Garpenberg: Department of Operational Efficiency, Swedish University of Agricultural Sciences, Internal Report 229. pp. 3-11.

DuBoy, J. and Norton, R., 1973, CHAC - A Programming Model of Mexican Agriculture. In L. Goreux and A. Manne (eds.), Multi-level Planning: Case Studies in Mexico. New York: American Elsevier. pp. 291-327.

Dyer, A. et al., 1979, "Implications of Goal Programming in Forest Resource Allocation", Forest Science, 24(4), pp. 535-543.

Energy, Mines and Resources, 1980, The National Energy Program, 1980. Ottawa: Energy, Mines and Resources.

Evans, R., 1974, Energy Plantations - Should We Grow Trees for Power-Plant Fuel?. Ottawa: Canadian Forestry Service, Environment Canada, Report VP-X-129.

Evers, R., Barkley, B. and Raitanen, W., 1983, Harvest and Yield. In Ontario Minnistry of Natural Resources, New Forests in Eastern Ontario: Hybrid Poplar. Toronto: Ontario Ministry of Natural Resources, Science and Technology Series, Volume 1. pp. 205-234.

Field, R., Dress, P. and Forston, J., 1980, "Complementary Linear and Goal Programming Procedures for Timber Harvest Scheduling", Forest Science, 26(1), pp. 121-133

Folk, H. and Hannon, B., 1974, "An Energy, Pollution and Employment Policy Model". In M. Macrakis (ed.), Energy: Demand, Conservation, and Institutional Problems. Cambridge: MIT Press. pp. 159-173.

Fookes, T., 1977, Social and Economic Impact of the Huntly Power Station: First Year Progress Report. Hamilton: Huntly Monitoring Project, University of Waikato, Working Paper 2.

Forrester, J., 1971, World Dynamics. Cambridge: Wright-Allen Press.

Friends of the Earth, 1983, 2025: Soft Energy Futures for Canadians. Ottawa: Energy, Mines and Resources.

Fry, R., 1984, Personal communication. Ontario Ministry of Energy.

Gardner, R., Lyon, I. and Clay, L., 1983, The Producer. In Ontario Ministry of Natural Resources, New Forests in Eastern Ontario: Hybrid Poplar. Toronto: Ontario Ministry of Natural Resources, Science and Technology Series, Volume 1. pp. 235-266.

Gilliland, M., 1975, "Energy Analysis and Public Policy", Science, 189(4208), pp. 1051-1056.

Gilliland, M., 1978, Energy Analysis: A New Public Policy Tool. Colorado: Westview Press, AAAS Selected Symposium 9.

Goicoechea, A., Hansen, D., and Duckstein, L., 1982, Multiobjective Decision Analysis with Engineering and Business Applications. New York: John Wiley and Sons.

Grantham, J. and Ellis, T., 1974, "Potentials of Wood for Producing Energy", Journal of Forestry, 72(9), pp. 552-556.

Hall, D., Barnard, G. and Moss, P., 1982, Biomass for Energy in the Developing Countries. Oxford: Pergamon Press.

Hall, D. and Moss, P., 1983, "Biomass for Energy in Developing Countries", GeoJournal, 7(1), pp. 5-14.

Hayes, D., 1981, Energy for Development: Third World Options. In M. Chatterji (ed.), Energy and Environment in the Developing Countries. New York: John Wiley and Sons. pp. 27-52.

Heady, E., 1973, Large-scale Models for Analysing and Predicting Potential Land Use Changes and their Economic and Social Impacts. In L. Whiting (ed.), Land Use Planning Seminar: Focus on Iowa. Iowa: Iowa State University, Centre for Agricultural and Rural Development. pp. 257-279.

Heady, E. and Hall, H., 1968, "Linear and Non-linear Spatial Models in Agricultural Competition, Land Use and Production Potential", American Journal of Agricultural Economics, 50(5), pp. 1539-1548.

Heady, E. and Spaulding, B., 1979, "Implications of Alternative Land Use Policies in the North Central Region", Regional Science Perspectives, 9(1), pp. 18-29.

Henderson, H., 1981, The Politics of the Solar Age. New York: Anchor Press.

Henderson, J., 1968, The Utilization of Agricultural Land: An Empirical Enquiry. In R. Smith, E. Taaffe and L. King (eds.), Readings in Economic Geography. Chicago: Rand McNally. pp. 281-286.

Herendeen, R., 1974, "Affluence and Energy Demand", Mechanical Engineering, 96(10), pp. 18-22.

Hewings, G., 1977, Regional Industrial Analysis and Development. London: Methuen and Co. Ltd.

Hill, M., 1968, "Goals Achievement Matrix for Evaluating Alternative Plans", Journal of American Institute of Planners, 34(1), pp. 19-29.

Hill, M., 1973, Planning for Multiple Objectives. Philadelphia: Regional Science Research Institute, Monograph Series No. 5.

Hill, M., and Werczberger, E., 1978, "Goal Programming and the Goals Achievement Matrix", International Regional Science Review, 3(2), pp. 165-181.

Hite, J. and Laurent, E., 1972, Environmental Planning: An Economic Analysis. New York: Praeger Publishers.

Houghton, T., 1974, Some Theoretical Aspects of Evaluation and Their Application to Plan-Making. In J. Perraton and R. Baxter (eds.), Models, Evaluations and Information Systems for Planners. Cambridge: MTP Construction. pp. 134-144.

Huettner, D., 1976, "Net Energy Analysis: An Economic Assessment", Science, 192(4235), pp. 101-104.

Ignizio, J., 1981, "The Determination of a Subset of Efficient Solutions via Goal Programming", Computer and Operations Research, 8, pp 9-16.

Ignizio, J., 1982, Linear Programming in Single and Multiple Objective Systems. New Jersey: Prentice-Hall.

Inman, R. and Salo, D., 1977, Silvicultural Energy Farms. In J. Pfeffer and J. Stukel (eds.), Proceedings, Fuels from Biomass Symposium. Urbana: The University of Illinois. pp. 29-41.

Inman, R., Salo, D. and McGurk, B., 1977, Silvicultural Biomass Farms, Volume IV: Site Specific Production Studies and Cost Analyses. Virginia: MITRE Corporation.

Intergroup Consulting Economists Ltd., 1978a, Liquid Fuels from Renewable Resources: Feasibility Study - Volume B, Conversion Studies. Ottawa: Environmental Management Service, Fisheries and Environment Canada.

Intergroup Consulting Economists Ltd., 1978b, Liquid Fuels from Renewable Resources: Feasibility Study - Volume C, Forest Studies. Ottawa: Environmental Management Service, Fisheries and Environment Canada.

Intergroup Consulting Economists Ltd., 1982, Availability and Cost of Forest Biomass in Canada. Ottawa: Canadian Forestry Service, Environment Canada, ENFOR Report P-224(1).

Isard, W., 1951, "Interregional and Regional Input-Output Analysis: A Model of a Space Economy", Review of Economics and Statistics, 33(4), pp. 318-328.

Isard, W., 1969, "Some Notes on the Linkage of Ecological and Economic Systems", Papers, Regional Science Association, 22, pp. 85-96.

Isard, W., 1972, Ecologic-Economic Analysis for Regional Development. New York: Free Press.

Isard, W., 1975, Introduction to Regional Science. New Jersey: Prentice-Hall.

Jacoby, H. and Loucks, D., 1972, "Combined Use of Optimization and Simulation Models in River Basin Planning", Water Resources Research, 8(6), pp. 1401-1414.

Jensen, R. and MacDonald, S., 1982, "Technique and Technology in Regional Input-Output", The Annals of Regional Science, 16(2), pp. 27-45.

Johnson, M. and Bennett, J., 1981, "Regional Environmental and Economic Impact Evaluation", Regional Science and Urban Economics, 11(2), pp. 215-230.

Just, J., 1974, Impacts of New Energy Technology Using Generalized Input-Output Analysis. In M. Macrakis (ed.), Energy: Demand, Conservation and Institutional Problems. Cambridge: MIT Press. pp. 113-127.

Kelly, R. and Spofford, W., 1977, Application of an Ecosystem Model to Water Quality Management: The Delaware Estuary. In C. Hall and J. Day (eds.), Ecosystem Modelling in Theory and Practice. New York: John Wiley and Sons. pp. 419-443.

Kliman, M., 1984, "Methanol, Natural Gas, and the Development of Alternative Transportation Fuels", Energy, 8(11), pp. 859-870.

Lakshmanan, T. and Nijkamp, P., 1980, Economic-Environmental-Energy Interactions. Boston: Martinus Nijhoff Publishing.

Land Evaluation Project, 1982, Conditions Affecting Evaluation of Lands for Agriculture in Northern and Eastern Ontario. Guelph: University School of Rural Planning and Development, University of Guelph, Report No. 3.

Lee, S., 1972, Goal Programming for Decision Analysis. Philadelphia: Auerbach Publishers Ltd.

Leistritz, F. and Chase, R., 1982, "Socioeconomic Impact Monitoring Systems: A Review and Evaluation", Journal of Environmental Management, 15(4), pp. 333-349.

Leistritz, F. and Murdock, S., 1981, The Socioeconomic Impact of Resource Development: Methods for Assessment. Colorado: Westview Press.

Leontief, W., and Strout, A., 1963, "Multiregional Input-Output Analysis". In T. Barna (ed.), Structural Interdependence and Economic Development. London: MacMillan and Co. Ltd. pp. 119-149.

Lichfield, N., 1971, "Cost-Benefit Analysis in Planning: A Critique of the Roskill Commission", Regional Studies, 5(3), pp. 157-183.

Lichfield, N., Kettle, P. and Whitbread, M., 1975, Evaluation in the Planning Process. Oxford: Pergamon Press.

Liebman, J., 1976, "Some Simple-minded Observations on the Role of Optimization in Public Systems Decision-making", Interfaces, 6(4), pp. 102-108.

Lindner, R., 1969, "The Economics of Increased Beef Production on Dairy Farms in Western Australia", Quarterly Review of Agricultural Economics, 22(3), pp. 147-164.

Lonergan, S., 1981, "A Methodological Framework for Resolving Ecological/Economic Problems", Papers, Regional Science Association, 48, pp. 117-133.

Lonergan, S., 1983, "A Simulation/Optimization Model for Natural Resource Planning", Resource Management and Optimization, 2(4), pp. 293-321.

Loucks, D., 1975, Planning for Multiple Goals. In C. Blitzer, P. Clark and L. Taylor (eds.), Economy-wide Models and Development Planning. Oxford: Oxford University Press. pp. 213-233.

Loucks, D., Stedinger, J. and Haith, D., 1981, Water Resource Systems and Planning and Analysis. New Jersey: Prentice-Hall.

Love, P., 1980, Biomass Energy in Canada: Its Potential Contribution to Future Energy Supply. Ottawa: Energy, Mines and Resources, Report ER-80-4E.

Lovins, A., 1977, Soft Energy Paths. New York: Harper Colophon.

Lovins, A., 1979, "Lovins on Soft Paths versus Hard Paths", Alternatives, 8(3/4), pp. 4-9.

Marks, D. and Cohon, J., 1975, An Application of Linear Programming to the Preliminary Analysis of River Basin Planning Alternatives. In H. Salkin and J. Saha (eds.), Studies in Linear Programming. New York: North Holland. pp. 251-271.

Matthews, W. and Siddiqi, T., 1981, Energy and Environmental Issues in the Developing Countries. In M. Chatterji (ed.), Energy and Environment in the Developing Countries. New York: John Wiley and Sons. pp. 53-67.

McAllister, D., 1982, Evaluation in Environmental Planning. Massachusetts: MIT Press.

McGrew, J., 1975, Goal Programming and Complex Problem Solving in Geography. Pennsylvania: Pennsylvania State University, Papers in Geography No. 12.

McKay, D. and Sutherland, R., 1978, Methanol in Ontario: A Preliminary Study. Toronto: Ontario Ministry of Energy.

McKean, R., 1958, Efficiency in Government Through Systems Analysis. New York: John Wiley and Sons.

Meadows, D. H., Meadows, D. L., Randers, J. and Behrens, W., 1972, The Limits to Growth. New York: Universe Books.

Meier, R., 1968, "Programming of Recreational Land Aquisition", Socio-Economic Planning Sciences, 2(1), pp. 15-24.

Meister, A., Heady, E., Nicol, K. and Strohbehn, R. 1976, U.S. Agricultural Production in Relation to Alternative Water, Environmental, and Export Policies. Iowa: Centre for Agricultural and Rural Development, University of Iowa, CARD Report 65.

Miller, H., 1983, Wood Energy Plantations - Diagnosis of Nutrient Deficiencies and the Prescription of Fertilizer Applications in Biomass Production. Maple: Ontario Tree Improvement and Forest Biomass Institute, Ontario Ministry of Natural Resources.

Miller, R. and Blair, P., 1985, Input-Output Analysis: Foundations and Extensions. Englewood Cliffs, N.J.: Prentice-Hall Inc.

Miller, W. and Byers, D., 1973, "Development and Display of Multiple-Objective Project Impacts", Water Resources Research, 9(1), pp. 11-20.

Mishan, E., 1976, Cost-Benefit Analysis. New York: Praeger.

Moran, L. and Nautiyal, J., 1981, Estimate of Costs of Energy Production from Hybrid Poplar in Ontario. Paper presented to the International Energy Agency Prgramme Groups A and B Meeting, Toronto, 1981.

Morgan, D., Neenan, M. and Zsuffa, L., 1983, Forest Biomass Energy and its Potential. Toronto: Ontario Ministry of Natural Resources.

Moses, L., 1955 "The Stability of Interregional Trading Patterns and Input-Output Analysis", American Economic Review, 45(5), pp. 803-832.

Muller, F., 1979, Energy and Environment in Interregional Input-Output Models. Boston: Martinus Nijhoff Publishing.

Murdock, S. and Leistritz, F., 1980, "Selecting Socioeconomic Assessment Models: A Discussion of Criteria and Selected Models", Journal of Environmental Management, 10(2), pp. 241-252.

Murdock, S., Leistritz, F. and Jones, L., 1979, "Interfacing Economic and Demographic Models for Rural Areas: Design and Methodological Considerations", Southern Journal of Agricultural Economics, 11(1), pp. 139-144.

Nash, H. (ed.), 1979, The Energy Controversy. San Francisco: Friends of the Earth.

Neenan, M. and Lyons, G., 1981, Short Rotation Forestry as a Source of Energy. In W. Palz, P. Chartier and D. Hall (eds.), Energy from Biomass. London: Applied Science Publishers. pp. 232-238.

Nijkamp, P., 1980, Environmental Policy Analysis. New York: John Wiley and Sons.

Odum, H. and Odum, E., 1981, Energy Basis for Man and Nature. New York: McGraw-Hill.

Office of Technology Assessment, 1980, Energy from Biological Processes. Washington: Office of Technology Assessment, U.S. Congress.

Ontario Energy Corporation, 1984, Methanol in Ontario: An Assessment of a Transportation Fuel Alternative. Toronto: Ontario Ministry of Energy.

Ontario Ministry of Agriculture and Food (OMAF) and Ontario Ministry of Natural Resources (OMNR), 1982, The Forestry Agricultural Resource Inventory in Eastern Ontario: A Land Use Inventory. Toronto: Ontario Ministry of Agriculture and Food and Ontario Ministry of Natural Resources.

Ontario Ministry of Energy, 1981, Alternative Transportation Fuels for Ontario: A Policy and Strategy. Toronto: Ontario Ministry of Energy

Ontario Ministry of Natural Resources, 1983, New Forests in Eastern Ontario: Hybrid Poplar. Toronto: Ontario Ministry of Natural Resources, Science and Technology Series, Volume 1.

Ouellette-Babin, D., 1982, Energy Input and Output of Grain Corn and Soybean Production. Toronto: Ontario Ministry of Agriculture and Food.

Overand, R. and Love, P., 1978, Tree Power: An Assessment of the Energy Potential of Forest Biomass in Canada. Ottawa: Energy, Mines and Resources, Report ER-78-1.

Paris, Q., 1981, "Multiple Optimal Solutions in Linear Programming Models", American Journal of Agricultural Economics, 63(4), pp. 724-727.

Peat, Marwick and Partners, 1981a, Wood Production and Conversion in Eastern Ontario: Phase 1 - Wood Supply, Conversion Technology and Markets. Toronto: Ontario Ministry of Energy.

Peat, Marwick and Partners, 1981b, Wood Production and Conversion in Eastern Ontario: Phase 2 - Preliminary Technical and Economic Assessment. Toronto: Ontario Ministry of Energy.

Peat, Marwick and Partners, 1982, Wood Production and Conversion in Eastern Ontario: Summary Report. Toronto: Ontario Ministry of Energy.

Peters, G., 1970, "Land Use Studies in Britain: A Review of the Literature with Special Reference to Applications of Cost-Benefit Analysis", Journal of Agricultural Economics, 21(2), pp. 171-214.

Pfeiffer, W., 1978, Economic Potentials of Hybrid Poplar Based Fibre Production as an Agricultural Enterprise in Eastern Ontario. Toronto: Ontario Ministry of Natural Resources.

Plotkin, S., 1980, "Energy from Biomass: The Environmental Effects", Environment, 22(9), pp. 6-13.

Pope, R. and Bottoms, K., 1976, Technical Users Manual - GOAL: Multiple Objective Programming. Colorado: Colorado State University, Range Science Department.

Power, G., Gillespie, W., Wittkowski, D, and Rink, R., 1980, "Computer Modelling of Boomtown Housing: The Fort McMurray Study", Canadian Journal of Regional Science, 3(1), pp. 30-48.

Rose, D., 1975, "Fuel Forest vs. Strip Mining: Fuel Production Alternatives", Journal of Forestry, 73(8), pp. 489-493.

Rose, D., 1977, "Cost of Producing Energy from Wood in Intensive Cultures", Journal of Environmental Management, 5(1), pp. 23-35.

Roseth, J., 1970, "Optimization in Planning", Royal Australian Institute of Planners Journal, 8(4), pp. 98-101.

Rothschild, B. and Balsinger, J., 1971, "A Linear Programming Solution to Salmon Management", Fishery Bulletin, 69, pp. 117-140.

Roy, B., 1971, "Problems and Methods with Multiple Objective Functions", Mathematical Programming, 1(2), pp. 239-266.

Sastry, C. and Anderson, H., 1980, "Clonal Variation in Gross Heat of Combustion in Juvenile Populus Hybrids", Canadian Journal of Forest Research, 10(3), pp. 245-249.

Sajdak, R., Lai, Y., Mroj, G. and Jurgensen, M., 1981, Forest Biomass for Energy: A Perspective. In D. Klass (ed.), Biomass as a Non-Fossil Fuel Source. Washington: ACS Symposium Series. pp. 21-48.

Schuler, A., Webster, H. and Meadows, J., 1977, "Goal Programming in Forest Management", Journal of Forestry, 75(6), pp. 320-324.

Science Council of Canada, 1977, Canada as a Conserver Society. Ottawa: Science Council of Canada.

Sekington, B., 1982, Wood and Peat as Fuels for Electricity Generation by Ontario Hydro. Toronto: Ontario Hydro.

Shefer, D., 1973, "Forecasting Industrial Air Pollution in the Haifa Bay Area with an Input-Output Model", Socio-Economic Planning Sciences, 7(5), pp. 397-406.

Shelton, I., Wall, G. and Dickinson, W., 1984, A Proposed Methodology for Mapping Provincial Soil Loss Potential. Guelph: Ontario Institute of Pedology.

Solomon, B. and Haynes, K., 1984, "A Survey and Critique of Multiobjective Power Plant Siting Decision Rules", Socio-Economic Planning Sciences, 18(2), pp 71-79.

Steenge, A., 1977, "Economic-Ecologic Analysis: A Note on Isards Approach", Journal of Regional Science, 17(1), pp. 97-105.

Sugden, R. and Williams, A., 1978, The Principles of Practical Cost-Benefit Analysis. Oxford: Oxford University Press.

Swartzman, G. and Van Dyne, G., 1972, "An Ecologically Based Simulation-Optimization Approach to Natural Resource Planning", Annual Review of Ecology and Systematics, 3, pp. 347-398.

Szego, G. and Kemp, C., 1973, "Energy Forests and Fuel Plantations", Chemtech, 3(5), pp. 275-284.

U.S. Department of Energy, 1978, Fuels from Biomass. Washington: Environmental Development Plan, U.S. Department of Energy.

Victor, P., 1972, Pollution: Economy and Environment. London: Allen and Unwin.

Wayman, M., 1978, Wood-Fired Electricity Generation in Eastern Ontario. Toronto: A report prepared for the Royal Commission on Electric Power Planning, Province of Ontario.

Werczberger, E., 1976, "A Goal Programming Model for Industrial Location Involving Environmental Considerations", Environment and Planning A, 8(2), pp. 173-188

Willis, C. and Perlack, R., 1980, "A Comparison of Generating Techniques and Goal Programming for Public Investment, Multiple Objective Decision Making", American Journal of Agricultural Economics, 62(1) pp. 66-73.

Wu, N. and Coppins, R., 1981, Linear Programming and Extensions. Toronto: McGraw-Hill.

Zsuffa, L., 1982, The Production of Wood for Energy. In W. Smith (ed.), Energy from Forest Biomass. New York: Academic Press Inc. pp. 5-17.

Zsuffa, L. and Morgan, D., 1983, Forest Biomass Energy Production - A Five Year Retrospect of the Work of Programme Group B - IEA/FE. Maple: Ontario Tree Improvement and Forest Biomass Institute, Ontario Ministry of Natural Resources.

APPENDIX A

PLANTATION MANAGEMENT SCHEDULES, COSTS AND REVENUES FOR ALTERNATIVE BIOMASS PLANTATION MANAGEMENT SYSTEMS

TABLE A1

SCHEDULE OF MANAGEMENT ACTIVITIES, COSTS AND REVENUES FOR ONE PLANTATION CYCLE OF A 35K PLANTATION SYSTEM: THE EXAMPLE OF KENYON TOWNSHIP, GLENGARY COUNTY

Year	Item	Revenues minus Costs	Discounted Net Revenues
0	Site preparation	-458.75	-458.75
1	Planting	-1,610.50	-1,519.56
2	No costs	0.00	0.00
3	Harvest:		
	Harvesting	-328.00	
	Transportation	-213.29	
	Revenues	1,360.00	
	Total	818.71	687.99
4	Weed Control	-212.50	
	Fertilize	-92.50	
	Total	-305.00	-242.72
5	Harvest	818.71	610.98
6	Fertilize	-92.50	-65.14
7	Harvest	818.71	545.81
8	Fertilize	-92.50	-58.18
9	Harvest	818.71	484.44
10	Fertilize	-92.50	-51.68
11	Harvest	818.71	430.90
Total net discounted revenues			364.09
Average annual net discounted revenues			33.10

See following page for list of assumptions and explanatory notes.

Assumptions

Distance to Cornwall: 32.2 kms.
Yield: 16 ODt/há./a.
Total biomass at harvest: 32 ODt/ha.
Delivered price: $42.50/ODt.
Rate of discount: 6%.

Notes

1. The plantation schedule and all costs, apart from harvesting and transportation are from Ontario Ministry of Natural Resouces (1983). Harvesting costs are based on Pfeiffer (1978). Transportation costs are based on Peat, Marwick and Partners (1981a).

2. Mechanical planting is assumed here. Accordingly, planting costs reported in Ontario Ministry of Natural Resources (1983) were reduced by two-thirds.

TABLE A2

SCHEDULE OF MANAGEMENT ACTIVITIES, COSTS AND REVENUES FOR ONE PLANTATION CYCLE OF A 4K PLANTATION SYSTEM: THE EXAMPLE OF KENYON TOWNSHIP, GLENGARY COUNTY

Year	Item	Revenues minus Costs	Discounted Net Revenues
0	Site preparation	-458.75	-458.75
1	Planting	-337.50	-318.40
2	Weed control	-275.00	-245.54
3-4	No costs	0.00	0.00
5	Harvest:		
	Harvesting	-643.34	
	Transportation	-279.95	
	Revenues	1,785.00	
	Total	861.71	637.07
6-9	No costs	0.00	0.00
10	Harvest	861.71	481.00
11-14	No costs	0.00	0.00
15	Harvest	861.71	359.05
16-19	No costs	0.00	0.00
20	Harvest	861.71	268.45
21-24	No costs	0.00	0.00
25	Harvest	861.71	200.86
Total net discounted revenues			930.14
Average annual net discounted revenues			37.21

See following page for list of assumptions and explanatory notes.

Assumptions

Distance to Cornwall: 32.2 kms.
Yield: 8.35 ODt/ha./a.
Total biomass at harvest: 42 ODt/ha.
Delivered price: $42.50/ODt.
Rate of discount: 6%.

Notes

1. The plantation schedule and all costs, apart from harvesting and transportation are from Ontario Ministry of Natural Resouces (1983). Harvesting costs and transportation costs are based on Peat, Marwick and Partners (1981a).

APPENDIX B

ESTIMATED TRANSPORTATION DISTANCES AND BIOMASS TRANSPORTATION COSTS

TABLE B1

AVERAGE DISTANCES FROM TOWNSHIPS IN EASTERN ONTARIO TO CORNWALL AND BIOMASS TRANSPORTATION COSTS

Township	Distance (kms.)	Cost ($/ODt)
Dundas Co.		
Matilda	51.0	10.56
Mountain	57.5	11.90
Williamsburgh	36.8	7.62
Winchester	46.4	9.60
Glengary Co.		
Charlottenburgh	17.1	3.54
Kenyon	32.2	6.67
Lancaster	30.5	6.31
Lochiel	42.3	8.76
Grenville Co.		
Augusta	80.4	16.64
Edwardsburgh	65.6	13.58
S. Gower	68.2	14.12
Oxford	75.8	15.69
Wolford	90.6	18.75
Prescott Co.		
Alfred	61.4	12.71
Caledonia	49.1	10.16
E. Hawkesbury	56.1	11.61
W. Hawkesbury	59.0	12.21
Longueuil	62.0	12.83
N. Plantagenet	61.0	12.63
S. Plantagenet	47.6	9.85
Russell Co.		
Cambridge	46.4	9.60
Clarence	62.8	13.00
Russell	54.0	11.18
Stormont Co.		
Cornwall	11.6	2.40
Finch	36.6	7.58
Osnabruck	23.7	4.91
Roxborough	28.6	5.92

1. Based on an average transportation rate of 20.7 cents/ODt/km.

APPENDIX C

COST AND REVENUE CALCULATIONS FOR A 9MW CO-GENERATION FACILITY, A 1000 tpd METHANOL PLANT AND AN INSTITUTIONAL HEATING COMPLEX

TABLE C1

COST AND REVENUE CALCULATIONS FOR A 9MW CO-GENERATION PLANT

A. Costs

Total capital cost	15,037,160
Operating costs	
Wood fuel - 121,496 ODt @ $42.50/ODt	5,163,580
Ash disposal	29,341
Operating staff/ (22)	415,356
Maintenance and materials	293,408
Administration	110,028
Insurance	27,507
Total	6,039,220

Annual costs

	Steam	Electricity	Total
Capital charges @ 14%	1,354,261	750,941	2,105,202
Operating costs	5,145,415	893,805	6,039,220
Total	6,499,676	1,644,676	8,144,422
Steam produced (net)			
10^6 BTU	1,327,260		
Unit cost ($/$10^6$ BTU)	4.90		
Electricity Produced			
10^6 KWH		61.825	
Unit cost (cents/KWH)		2.66	

B. Revenues

1. Total revenues

Electricity - 61.825 x 10^4 KWH @ 3.11 cents/KWH	1,922,758
Steam - 1,327,269 x 10^4 BTU @ $5.00/MM BTU	6,636,300

2. Net revenues

	Steam	Electricity	Total
Costs	6,499,676	1,644,746	8,144,422
Revenues	6,636,300	1,922,758	8,559,058
Balance	136,624	278,012	414,636

Revenues per unit of feedstock: $414,636/121,496 ODt = $3.41/ODt

Notes

1. Cost information is based on Peat, Marwick and Partners (1981b). See Chapter 5, Section 5.3.3 for a description of amendments.

TABLE C2

COST AND REVENUE CALCULATIONS FOR A 1,000 tpd
METHANOL PLANT

A. Costs

Total capital cost	90,000,000
Annual costs	
Capital @ 14%	16,397,964
Power	195,822
Labour	872,685
Supervision and administration	349,074
Water	749,232
Maintenance	3,643,922
Insurance and taxes	2,601,027
General overheads	621,522
Sub-total	25,431,248
Wood - 125,140 ODt @ $42.50/ODt	5,318,450
Methane	38,104,407
Total	68,854,105
Methanol produced	
Tonnes	330,000
Litres (1263.8 l/tonne)	4.17×10^{8}
Unit costs	
$/tonne	208.65
cents/litre	16.50

B. Revenues

1. Cost of methanol

Energy value of 1.0 tonne of methanol: 1.0 x 1,263.8 litres x 16,938 BTU/litre x 1,055 BTU/joule = 22.6 GJ/tonne.

Cost per GJ: $208.65/22.6 = $9.23/GJ

2. Cost of gasoline from imported oil

Energy value of 1.0 barrel of oil: 1.0 x 159 litres x 32,819 BTU/litre x 1,055 BTU/joule = 5.51 GJ/barrel.

Cost per GJ:	$38.85/5.51 =	$7.05/GJ
	Refining	$1.31/GJ
	Total	$8.36/GJ

3. Net Revenues

Cost of gasoline minus cost of methanol: $8.36 - $9.23 = -$0.87/GJ

Total annual net revenues: -$0.87 x 22.6 x 330,000 = -$6.488 x 10^6

Net revenues per ODt of feedstock: -$6.488 x 10^6/125,140 = -$51.85/ODt

Notes

1. Cost information is based on Intergroup Consulting Economists Ltd. (1978). See Chapter 5, Section 5.3.3 for a description of amendments.

TABLE C3

COST AND REVENUE CALCULATIONS FOR AN INSTITUTIONAL HEATING COMPLEX

A. Costs

1. Wood-fired system

Total capital cost	553,991
Annual costs	
Capital cost @ 14%	77,559
Maintenance costs	13,754
Labour	4,400
Wood fuel - 2,365 ODt @ $42.50/ODt	100,512
Total	196,225
Total energy output	3.69×10^4 GJ/a.

2. Oil-fired system

Total capital cost	153,122
Annual costs	
Capital cost @ 14%	21,437
Maintenance costs	3,668
Fuel - 207,100 Imp. gallons of fuel oil	195,300
Total	220,405
Total energy output	3.69×10^4 GJ/a.

B. Revenues

Cost of oil-fired system minus cost of wood-fired system: 220,405 - 196,225 = $24,180/a.

Revenues per unit of feedstock: $24,180/2,365 ODt = $10.22

Notes

1. All cost information, excluding costs for wood fuel and labour, is based on Dick Consulting Ltd. (1981a). The wood fuel cost is that assumed throughout this study. Labour costs are based on rates quoted in Peat, Marwick and Partners (1981a).

2. Only labour that is required in addition to that currently employed in the oil-fired heating plant is accounted for. The additional labour is for the operation of an overhead loader for an annual 3 month period. One chief operator and four shift operators are required to run the heating plant.

3. The estimate of total energy output is based on the assumption that the plant will operate at peak capacity for one-third of the time ($10,548 \times 10^4$ KJ/hour = 3.08×10^4 GJ/a.) and at base load for the remainder ($1,055 \times 10^4$ KJ/hour = 0.61×10^4 GJ/a.).

APPENDIX D

TRANSPORTATION ENERGY COEFFICIENTS

TABLE D1

TRANSPORTATION ENERGY COEFFICIENTS

Township	Distance (kms.)	Energy Coefficients (GJ/ODt)	35K (GJ/ha./a.)	4K (GJ/ha./a.)
Dundas Co.				
Matilda	51.0	0.110	1.76	0.92
Mountain	57.5	0.124	1.98	1.04
Williamsburgh	36.8	0.082	1.31	0.68
Winchester	46.4	0.101	1.62	0.84
Glengary Co.				
Charlottenburgh	17.1	0.042	0.67	0.35
Kenyon	32.2	0.073	1.17	0.61
Lancaster	30.5	0.070	1.12	0.58
Lothiel	42.3	0.093	1.49	0.78
Grenville Co.				
Augusta	80.4	0.170	2.72	1.42
Edwardsburgh	65.6	0.140	2.24	1.17
S. Gower	68.2	0.146	2.34	1.22
Oxford	75.8	0.161	2.58	1.34
Wolford	90.6	0.190	3.04	1.59
Prescott Co.				
Alfred	61.4	0.132	2.11	1.10
Caledonia	49.1	0.107	1.71	0.89
E. Hawkesbury	56.1	0.121	1.94	1.01
W. Hawkesbury	59.0	0.127	2.03	1.06
Longueuil	62.0	0.133	2.13	1.11
N. Plantagenet	61.0	0.131	2.10	1.09
S. Plantagenet	47.6	0.104	1.66	0.87
Russell Co.				
Cambridge	46.4	0.102	1.63	0.85
Clarence	62.8	0.135	2.16	1.13
Russell	54.0	0.117	1.87	0.98
Stormont Co.				
Cornwall	11.6	0.032	0.51	0.27
Finch	36.6	0.082	1.31	0.68
Osnabruck	23.7	0.056	0.90	0.47
Roxborough	28.6	0.066	1.06	0.55

APPENDIX E

GOAL RELATIONSHIPS: SELECTED RESULTS OF THE ANALYSIS

TABLE E1

GOAL RELATIONSHIPS WITH BIOMASS SUPPLY PRICE
INCREASED TO $45.00/ODt

Goal	Scenario 1 Priority	Scenario 1 Goal Level	Scenario 2 Priority	Scenario 2 Goal Level	Scenario 3 Priority	Scenario 3 Goal Level	Scenario 4 Priority	Scenario 4 Goal Level
Production Economics	1	2.36 (100%)	2*	1.12 (47%)	3	1.12 (47%)	3	1.41 (60%)
Conversion Economics	2*	0.23 (50%)	1	0.46 (100%)	2*	-26.60 (-5,753%)	2*	0.26 (57%)
Regional Employment	3	0.49 (51%)	3	0.74 (76%)	1	0.96 (100%)	4	0.54 (56%)
Regional Income	4	9.32 (28%)	4	11.30 (34%)	4	33.19 (100%)	5	8.97 (27%)
Energy Efficiency	5	2.66 (45%)	5	5.90 (100%)	5	-7.25 (-123%)	6	3.05 (52%)
Environmental Quality	6	0.15 (37%)	6	0.35 (-172%)	6	0.35 (-172%)	1	0.09 (100%)

Notes
1. All unbracketed values reported under Goal Level are x 10^4
2. * indicates priority level at which solution is determined, assuming multiple optima do not exist.

TABLE E2

GOAL RELATIONSHIPS WITH BIOMASS SUPPLY PRICE
DECREASED TO $40.00/ODt

Goal	Scenario 1 Priority	Scenario 1 Goal Level	Scenario 2 Priority	Scenario 2 Goal Level	Scenario 3 Priority	Scenario 3 Goal Level	Scenario 4 Priority	Scenario 4 Goal Level
Production Economics	1	0.96 (100%)	2*	-1.89 (-196%)	3	-1.89 (-196%)	3	-0.55 (-57%)
Conversion Economics	2*	0.66 (23%)	1	2.91 (100%)	2*	-24.26 (-832%)	2*	1.61 (55%)
Regional Employment	3	0.29 (30%)	3	0.74 (76%)	1	0.96 (100%)	4	0.54 (56%)
Regional Income	4	6.18 (19%)	4	11.30 (34%)	4	33.19 (100%)	5	8.97 (27%)
Energy Efficiency	5	1.13 (19%)	5	5.90 (100%)	5	-7.25 (-123%)	6	3.05 (52%)
Environmental Quality	6	0.05 (148%)	6	0.35 (-172%)	6	0.35 (-172%)	1	0.09 (100%)

Notes
1. All unbracketed values reported under Goal Level are x 10^4
2. * indicates priority level at which solution is determined, assuming multiple optima do not exist.

TABLE E3

GOAL RELATIONSHIPS UNDER THE ASSUMPTION THAT METHANE IS OBTAINED FROM A SOLID WASTE PLANT

Goal	Scenario 1 Priority	Scenario 1 Goal Level	Scenario 2 Priority	Scenario 2 Goal Level	Scenario 3 Priority	Scenario 3 Goal Level	Scenario 4 Priority	Scenario 4 Goal Level
Production Economics	1	1.54 (100%)	2*	-0.39 (-25%)	3	-0.39 (-25%)	2*	-0.39 (-25%)
Conversion Economics	2*	0.60 (36%)	1	1.69 (100%)	2*	-25.42 (-1,506%)	3	-25.42 (-1,506%)
Regional Employment	3	0.37 (39%)	3	0.74 (76%)	1	0.96 (100%)	4	0.96 (100%)
Regional Income	4	7.57 (23%)	4	11.30 (34%)	4	33.19 (100%)	5	33.19 (100%)
Energy Efficiency	5	1.87 (7%)	5	5.90 (21%)	5	27.70 (100%)	1	27.70 (100%)
Environmental Quality	6	0.10 (90%)	6	0.35 (-172%)	6	0.35 (-172%)	6	0.35 (-172%)

Notes

1. All unbracketed values reported under Goal Level are x 10^4
2. * indicates priority level at which solution is determined, assuming multiple optima do not exist.

TABLE E4

GOAL RELATIONSHIPS WITH THE CO-GENERATION FACILITY
CONSTRAINED TO A 9MW OUTPUT LEVEL

Goal	Scenario 1 Priority	Scenario 1 Goal Level	Scenario 2 Priority	Scenario 2 Goal Level	Scenario 3 Priority	Scenario 3 Goal Level	Scenario 4 Priority	Scenario 4 Goal Level
Production Economics	1	1.54 (100%)	2*	1.51 (98%)	3	-0.39 (-25%)	3*	1.51 (98%)
Conversion Economics	2*	-2.00 (-455%)	1	0.44 (100%)	2*	-18.71 (-4,267%)	2	0.44 (100%)
Regional Employment	3	0.40 (44%)	3	0.32 (35%)	1	0.91 (100%)	4	0.32 (35%)
Regional Income	4	9.67 (35%)	4	6.66 (24%)	4	27.77 (100%)	5	6.66 (24%)
Energy Efficiency	5	0.61 (41%)	5	1.29 (85%)	5	-4.00 (-265%)	6	1.29 (85%)
Environmental Quality	6	0.10 (90%)	6	0.06 (135%)	6	0.35 (-172%)	1	0.06 (135%)

Notes
1. All unbracketed values reported under Goal Level are x 10^4
2. * indicates priority level at which solution is determined, assuming multiple optima do not exist.

APPENDIX F

LIST OF VARIABLES, COEFFICIENTS AND RIGHT-HAND-SIDES IN THE EASTERN ONTARIO RESOURCE ASSESSMENT MODEL

LIST OF VARIABLES, COEFFICIENTS AND RIGHT-HAND-SIDES

a_{ij} is the amount of land in township i devoted to hybrid poplar plantations under management system j.

A_i is the total amount of land available in township i.

C_{ijt} are the per hectare costs for hybrid poplar production in area i, under management system j, in year t.

C_h are the annual costs per oven dried tonne of wood input for biomass conversion facility h.

e_h^{co} is the gross energy output, per oven dried tonne of biomass input, from conversion facility h.

e_h^{cn} are the energy inputs to the conversion process, expressed in units per oven dried tonne of input, in energy conversion facility h.

e_{ij}^{pn} are the per hectare energy inputs to biomass plantations in township i, under management system j.

E is a target level for total net energy production from the regional biomass energy system.

I_j is the length, in years, of the plantation cycle for management system j.

l_{ij}^p is the number of worker-hours required per hectare for plantation operations under management system j.

l_h^c is the number of worker-hours required per oven dried tonne of biomass input to operate conversion facility h.

L is a target for regional labour generation, expressed in worker-hours per year.

m_{ij}^p is the per hectare dollar expenditure on plantation operations under management system j.

m_h^c is the dollar expenditure per unit of biomass required for the operation of conversion facility h.

M is a target for regional income generation, expressed in dollars per year.

o_j is the rotation length for management system j.

q_h is the total amount of biomass, measured in oven dried tonnes, allocated to conversion facility h.

Q_h^U is an upper limit on the size of conversion facility h.

Q_h^L is a lower limit on the size of conversion facility h.

Q_h^* is a specified size for conversion facility h.

r is the rate of discount.

R_{ijt} are the per hectare returns to hybrid poplar production in area i, under management system j, in year t.

R_h are the annual returns per oven dried tonne of wood input for biomass conversion facility h.

s_{ij}^p is a measure of the environmental disruption per hectare caused as a result of poplar cultivation in township i, under management system j.

s_h^c is a measure of the environmental disruption caused annually per oven dried tonne of wood processed in conversion facility h.

S^p is a target expressing the acceptable level of environmental disruption as a consequence of poplar cultivation.

S^c is a target expressing the acceptable level of environmental disruption as consequence of energy conversion processes.

t is time, in years.

V^p is a target level for the annual level of return to hybrid poplar production in the region.

V^c is a target level for annual returns to energy conversion in the region.

Y_{ij} is the yield of poplar biomass in region i and grown under management system j.