Chapter 1

INTRODUCTION AND THE OUTLINE OF THE STUDY

In this chapter, changes in energy use in Australia arising from the oil price shock of 1973-74 are briefly discussed. This is followed by an overview of studies concerning the nature of the functional relationship between energy and capital. Then, the statement of the problem follows. Afterwards, the model used, the justification and the objectives of this study are discussed.

1.1 Introduction

The oil price shock of 1973-74 and its aftermath in 1979 was a watershed in the economic history of both developed and developing countries. Since that time, a series of price changes unpredictable in magnitude and direction took place which forced producers and consumers to change directions several times in their search for optimal combination of energy and non-energy inputs (Gowdy and Miller 1987b, p. 1387).

In Australia, the effect of this oil price shock was observed in changes in total energy consumption and subsequently in the slowdown of the growth of Gross Domestic Product. The changes took place in the mix of energy usage in particular sectors and in the absolute level of energy use (Department of Resources and Energy 1987 pp. 1-5, Marks 1986, pp. 49-52). There has been a decline in energy consumption over the period 1960-61 to 1982-83. The average annual growth rate of energy consumption during the period 1960-61 to 1971-72 was 5.1 per cent, for 1971-72 to 1977-78 the rate was 4.2 per cent per annum and for the last six years up to 1982-83 it fell to 0.9 per cent. Further, there has been a transition from oil to other fuels e.g. natural gas and coal, and the trend is continuing. The share of energy consumption by fuel-type is shown in Table 1.1.

It is observed from Table 1.1 that the share of oil to total energy consumption has declined from a peak of about 51 per cent in 1973-74 to 39.5 per cent in 1984-85, reflecting substitution and conservation of petroleum fuels over the period. This is also evident in Table 1.2.

Table 1.2 indicates that the share of petroleum products over the 1973-74 to 1984-85 period decreased while the share of coal, gas and electricity increased in stationary applications. This was due to substitution and conservation measures taken in relation to the use of petroleum fuels. (Department of Resources and Energy 1987, p. 6.) However, the share of petroleum products usage in mobile applications has not changed due to the lack of economically viable substitutes. In 1973-74 and in 1984-85, petroleum products comprised over 99 per cent of mobile applications (Department of Resources and Energy 1987, p. 6).

Table 1.1.

Percentage Share of Energy Consumed by Fuel Type in Australia

Fuel Type	Year	
	1973-74	1984-85
Oil	51.0	39.5
Natural gas	6.8	15.5
Coal	35.2	38.7
Renewables (Hydroelectricity, wood and bagasse)	7.0	6.3
Total:	100.0	100.0

Source: Department of Resources and Energy 1987, p. 5.

Table 1.2.

Share of Energy Consumed by Fuel Type in Stationary Applications

(Industrial and Residential Use Other Than Used in Transport).

Fuel Type	Year	
	1973-74	1984-85
Petroleum products	16.3	8.2
Coal, Gas and Electricity	45.4	58.2
Other fuels	38.3	33.6
Total:	100.0	100.0

Source: Department of Resources and Energy 1987, p. 5.

The conservation of petroleum fuels has been reflected in the gradually decreasing use of oil in its different applications. This is shown in Table 1.3.

Table 1.3.

Percentage Share of Energy Provided by Oil for Different Applications.

Applications	Year	
	1973-74	1984-85
Fuel for electricity generation	7.0	4.0
Total final energy consumption[1]		
(a) residential/commercial use	24.0	8.0
(b) manufacturing use	34.0	19.0

Source: Marks 1986, p. 50.

Higher energy prices in Australia, according to Marks (1986), encouraged the substitution of other factors of production, for energy in general and oil in particular.

The energy intensity[2] of the economy has declined since 1979-1980 despite the continued development of energy intensive industries, reflecting inter alia, the increased impact of energy conservation measures. Oil intensity has also declined significantly since 1977-78 reflecting the substitution away from this fuel (Department of Energy and Resources 1987, pp. 10-12).

It was mentioned earlier that the oil price shock had a slowdown impact on the growth of Gross Domestic Product in Australia. The growth of total energy consumption and Gross Domestic Product exhibited a close relationship as is evident in Table 1.4.

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1 Total final energy consumption is defined here as the amount of energy consumed in the non-conversion sector end-use devices and is equal to total energy consumption less energy consumption and loss in the production of derived fuel by the conversion sectors (electricity and oil refining) (Department of Resources and Energy 1987, p. 26).

2 Energy-intensity has been defined as the amount of total energy consumed per billion dollars of Gross Domestic Product at 1979-80 prices; the same with oil intensity (Department of Resources and Energy 1987, p. 11).

Table 1.4.

Growth of Gross Domestic Product (GDP) and Total Energy Consumption (TEC) in Australia.

Year	Growth of GDP	Growth of TEC
1960-61 to 1973-74	5.3	5.3
1973-74 to 1977-78	2.1	3.4
1977-78 to 1981-82	2.9	2.1
1981-82 to 1982-83	-1.0	-3.6
1982-83 to 1984-85	5.1	3.9

Source: Department of Resources and Energy 1987, p. 3.

Table 1.4 indicates that the average annual growth of Gross Domestic Product and total energy consumption were identical from 1960-61 to 1973-74. In subsequent years, the growth of total energy consumption declined due to the rise in energy prices. Simultaneously, the growth of Gross Domestic Product declined although not to the same extent as total energy consumption.

The nature of the functional relationship between energy and capital or the growth in productivity has been studied using econometric methods and production function analysis. Important studies were carried out by Jorgenson and Hudson (1974), Berndt and Wood (1975), Griffen and Gregory (1976), Jorgenson (1980), Baily (1982), Hunt (1984) and Kilpatrick and Naisbitt (1988). Despite controversial findings concerning substitutability between capital and energy, the conclusive evidence of the above studies, however, demonstrated a complementary relationship between energy and capital (Jorgenson and Hudson 1974, Berndt and Wood 1975, Jorgenson 1980, Baily 1982 and Hunt 1984). Jorgenson makes the claim that since the mid 1970s the slowdown in productivity in the United States has been largely due to the complementarity between capital and energy. Higher energy prices, he argues, makes investment in capital equipment more expensive, thereby discouraging capital investment and causing a slowdown in the growth of the capital-labour ratio with a consequent slowdown in productivity growth. Similar findings were obtained by Hunt (1984) and Kilpatrick and Naisbitt (1988) for the United Kingdom.

1.2 Statement of The Problem

The rise in energy prices, its impact and its critical role in the economy, as evident from the above analyses, highlights the need to analyse the energy use patterns in the economy.

It was mentioned earlier, that the oil price shock of 1973-74 forced producers and consumers to change directions several times in their search for optimal combination of energy and non-energy inputs. The underlying mechanism of this search for optimum input combinations can be explained as follows. The oil price shock brought about changes in relative prices of energy and non-energy resources, and changes in relative prices of different energy types.

When there has been such changes in relative prices of resources (energy and non-energy), a profit maximizing firm (industry) with a given outlay and having two energy inputs, coal and oil for example, will substitute coal for oil if the price of oil increases compared to that of coal. The substitution process will continue until the cost of production is minimized. Similar behaviour may be noticed for any other profit maximizing firm (industry) with changes in relative prices between energy and non-energy inputs or within non-energy inputs. In broader terminology, the changes in relative prices of resources bring about changes in production technology. So, changes in the technology of production have bearings on the amount of energy and non-energy input used over time and space by a firm (industry).

In a similar way, changes in the relative prices of commodities lead to changes in the consumers' buying patterns until the utilities so derived from new spending are maximised (assuming that consumers are utility maximizing). The changes in buying patterns are reflected in changes in the share of commodity baskets. The changes in commodity baskets influence the amount of energy and non-energy goods and services consumed.

The Department of Resources and Energy (1987) indicated particular sectors or groups of sectors being either more energy efficient or less energy efficient[3] , by looking at the energy intensity value for each sector over the years. According to this Department, energy efficiency decreased in the agriculture, mining, electricity and service sectors during the period 1973-74 to 1980-81, while the energy efficiency increased in the manufacturing sector. Among the manufacturing sectors, energy efficiency increased in food, paper, chemicals, the non-metallic minerals, basic metals, transport equipment and in miscellaneous manufacturing sectors. But, it decreased in textiles, fabricated metal and wood sectors (Department of Resources and Energy 1987, Tables 4 & 5, pp. 13-14). This notion of either increase or decrease in energy efficiency, however, is misleading, as the reported energy intensity value for different industries reflects

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3 A sector may be said to be energy efficient if it requires less and less amounts of energy unit (petajoules) per dollar of its output over time (Gowdy and Miller 1987b, p. 1393).

the direct energy use only. Thus, a relevant question to investigate is, whether a different pattern of energy efficiency among sectors appears when the indirect (that is, energy embodied in non-energy inputs required in production) as well as the direct levels of energy usage are considered. Therefore, it is necessary to investigate the main determinants of changes in indirect energy use which are, according to Gowdy and Miller (1987b, p. 1393), changes in energy efficiency or energy intensiveness of direct inputs, and changes in energy output efficiency[4] .

The foregoing discussion suggests that the total changes in energy use in Australia arising from the oil price shock of 1973-74 may originate from changes in the technology of production and changes in final demand. Hence, the main focus of the present study is to investigate to what extent the total changes in energy use were technology induced and demand induced.

1.3 Input-Output Analysis

The nature of the problem discussed above can be effectively analysed by using input-output methods. Input-Output analysis provides a useful framework for tracing and determining energy use required to deliver a product to final demand. Using input-output analysis, a product, either goods or a service, is identified and a list of goods and services directly required to deliver the product is compiled. These goods and services may include fuels (direct energy) and non-energy goods and services. The non-energy goods are then analysed to determine the inputs to their production process which include again some fuels and non-energy goods and services. This process traces inputs back to primary resources: the first round of energy inputs is the direct energy requirement; subsequent rounds of energy inputs comprise the indirect energy requirement. The sum of these two is the total energy requirement. For example, the energy used in assembling automobiles includes a direct energy requirement, while the energy embodied in the materials employed at the assembly plant (tyres, engines, glass, rubber etc.) would comprise indirect energy requirements.

Due to the limitation of space, the detailed discussion on the basic concepts and assumptions of the input-output analysis was not done here. The basic concepts, assumptions and the analytical procedures related to input-output analysis are well described and analysed in every introductory text book on Input-Output Analysis (Yan 1969, Richardson 1972, Bulmer-Thomas 1982, Hewings 1985, Miller and Blair 1985).

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4 An energy output efficiency means if less and less amounts of energy units (petajoules) are required per petajoule of output by an energy producing sector over time (Gowdy and Miller 1987b, p. 1393).

1.4 Justification of the Study

The input-output studies in Australia, have to date considered mostly the impact of high oil prices on different sectors of the economy (Vincent et al 1979, 1980). These energy economic studies are basically simulation studies based on the 1968-69 national input-output tables under different assumptions. After the oil price shock, there have been changes in the use of production technology due to changes in relative prices, the simulation study of the sort, based on the 1968-69 input-output tables, is rather misleading. James (1980b) constructed energy input-output tables for 1968-69 to look at the energy content of the Australian production. He proposed an accounting framework designed to systematize energy and economic data and provide a flexible basis for the construction of input-output models of different kinds. His contribution is substantial but the study is based on the outdated 1968-69 input-output tables.

After the oil price shock, no systematic energy economic study has been undertaken in Australia to investigate the pattern and the extent of total energy use by different sectors of the economy. Although, the Department of Resources and Energy (1987) has shown the energy use by sectors and fuel types during the period 1973-74 to 1984-85, the findings provide only the direct energy use, having no reflection on indirect energy use. That is, the amount of energy embodied in non-energy inputs used as intermediate inputs in the production process, has not been considered. It may be the case that direct energy use may decrease due to rises in energy prices but it could happen at a cost of increased indirect energy use. In this situation, treatment of a sector as either a heavy energy user or an energy saver from its apparently high or low energy intensity value could be misleading from the policy point of view.

This is the first time in Australia, a comparative study of energy use is being carried out by constructing two energy input-output tables, one for 1974-75 and another for 1980-81, reflecting the oil price shock and the post oil price shock situations, respectively.

The present study of comparative statics will indicate:

i. which particular sectors in the economy are the heaviest users of energy (i.e the most energy intensive industries);

ii. which sectors are the energy saving sectors and from where these changes in energy use originate; and

iii. to what extent these changes arise from changes in technology and changes in consumer preferences or final demand.

Whatever factors are accounting for the changes in energy use in different sectors of the economy, the present study will provide an insight into the likely interacting forces. An understanding of these factors may contribute to better policy formulation.

So, one needs a careful analysis of the inter-industry linkages among the energy sectors, and the energy and non-energy sectors. As energy input-output analysis recognizes the interdependence of all sectors of the economy and their contribution to energy embodied in specific goods and services, the choice of an input-output approach for this study is an appropriate one.

1.5 Objectives of the Study

The objective of this study is to estimate the change in energy intensiveness of each major sector of the economy. It has been mentioned earlier that a sector, in addition to consuming direct energy, consumes also indirect energy, that is, energy embodied in non-energy inputs. Thus, a change in energy consumption must take into account the changes in both direct and indirect or induced changes in energy use. These direct and indirect changes in energy use originate from changes in the technology of production. Further changes in energy use may originate from changes in the buying pattern of consumers for the final goods and services. The changes in the level and mix of buying patterns have bearings on the amount of energy use. Thus, the objective of this study is to investigate: To what extent the total changes in energy use in Australia are technology induced and demand induced. As mentioned earlier, the technology induced changes in energy use further consist of (i) direct changes, and (ii) indirect changes in energy use. The indirect change in energy use consists of (a) indirect change in the level of consumption; (b) indirect change in energy mix; and (c) indirect change in non-energy input mix.

The demand induced changes in energy use include (i) changes in demand mix, and (ii) changes in the level of final demand.

Thus, the **main factors** considered here are to investigate the changes in the overall energy use that result from:

i. the substitution of one type of energy input for another;

ii. the substitution among non-energy inputs;

iii. the effect of the size and mix of final demand.

1.6 Organisation of This Study

The present study is comprised of five chapters. In Chapter 2, the method of analysis of this study is presented including a discussion on the framework of input-output analysis, the theoretical construction of energy input-output tables, previous energy studies in overseas countries and in Australia, and the approaches adopted in this study. Construction of the energy make matrix, the energy absorption matrix and the energy flow matrix are discussed in Chapter 3 ultimately to construct the energy input-output tables for Australia. The interpretation of results and the limitation of the study are provided in Chapter 4. Finally, Chapter 5 draws the summary, conclusion, and policy implications of the study together with the guidelines for future research.

Chapter 2

METHODS OF ANALYSIS

This chapter first introduces a discussion of the use of input-output analysis in the context of the present study. Next, the general method of constructing energy input-output tables is discussed. The energy input-output studies follow the next. Then the procedures used in this study are mentioned followed by a note on the limitations associated with the energy input-output analysis. Lastly, the data requirements and data sources are described.

2.1 Input-Output Analysis and its Application to Energy Studies

Input-output analysis provides a descriptive framework for showing the relationship between industries and sectors and between inputs and outputs. Given certain assumptions on the nature of the production function, it is an analytical tool for measuring the impact of autonomous changes in final demand on an economy's output, employment and income (Richardson 1972, p. 14).

The 'Leontief inverse' matrix is at the core of the input-output model. The elements of the inverse provide the interdependency coefficients (r_{ij}'s) which measure the total (direct plus indirect) requirements for commodity i (i = 1, 2 ... n) when one unit of commodity j (j = 1, 2 ... m) is required by final users. Once indirect and direct effects of an exogenous increase in final demand on each sectoral gross output is known, it is possible under certain assumptions, to estimate the requirements of certain factors such as employment and capital (Chowdhury 1983, p. 38).

In chapter 1, it was mentioned that the objective of the study is to observe to what extent the total changes in energy use arising from oil price increases in 1973-74 and in 1979 in Australia were technology induced and demand induced. Input-output analysis as a tool has been chosen especially for this purpose on the assumption that the input-output coefficients of the Leontief system represent structural parameters of an economic system with identifiable technological parameters (Klein 1953, pp. 131-4). The direct requirements matrix (A) of the input-output model represents a set of linear equations describing the amounts and kinds of industry outputs consumed by a given industry to produce one unit of its output. Presumably, the combination of inputs chosen by a firm is one of maximizing its present net worth, given the present and expected prices, technology, raw materials supply, government regulation and so on. When the price of one factor input, for example, energy, changes significantly it can be expected that each industry would ultimately rearrange its buying pattern to a new set of net worth maximizing conditions. It would also raise the price of its output, which would affect other industries that consume this output. When the iterative adjustments are completed by all industries affected by the higher price of energy, it is possible to get what is essentially a new 'A' matrix and a new set of output prices (each industry adjustment takes into account the projected response of consumers to increased output price, a factor influencing the industry's willingness to raise prices rather than change production processes). The new matrix thus represents an attempt to anticipate the results arising from long-term energy prices and government policies as these long-term energy prices and policies were designed presumably to encourage greater efficiency in energy consumption (Ford Foundation 1974, p. 46). A calculation employing such a matrix assumes that all industries adopt all economically-feasible technological changes assessing the given energy price increase.

However, there has been controversy on the interpretation, understanding and adequacy of input-output coefficients of the Leontief system to represent technological and structural parameters (Morishima 1956a, p. 65). Conceptual weaknesses, shortcomings and even the rationale behind the Leontief system have been cited by Dorfman (1954), Hatanaka (1960), Yan (1969), Richardson (1972), Baumol (1977, p. 537) and Pleeter (1980).

Despite the conceptual weaknesses and shortcomings of the Leontief system of input-output modelling, it has been widely used by economists, engineers, social scientists and different institutions throughout the world for different purposes. Among its many usages, the input-output model has been applied particularly to energy economics to investigate the nature and pattern of energy use by different sectors of the economy, energy intensities of products (Reardon 1973, Herendeen 1974, Hannon 1982, Hannon and Blazeck 1984, Lesuis and Muller 1975, Gowdy and Miller 1987a, 1987b, Gowdy et al. 1987), and environmental impacts arising from the residuals/pollution from different kinds of energy sources (Leontief and Ford 1972, Folk and Hannon 1974, Carter 1974, Istvan 1974, Just 1974, Fisher 1975, Miernyk 1977, Almon et al. 1974). Energy economic input-output analysis also has been used as a core in neoclassical econometric models, for example by the Brooking Institute, USA, Forsund and Strom (1974), Preston (1975), Evans (1969) and Nordhaus (1973). Further, it has also been used in other programming models to simulate the effect of different policies on energy, economic growth and other fields of analytical interest (Parikh 1976, and Connoll et al. 1977).

James (1983) suggested that a generalized input-output model incorporating energy flows and environmental factors could be usefully constructed for Australia. The energy economic input-output model thus constructed could be used for a variety of policy applications. These would include:

(i) determination of economy-wide price changes following any alteration of energy costs or the imposition of taxes or price controls on specific fuels;

(ii) studies on the energy efficiency of energy use patterns through energy budgeting analysis;

(iii) assessing the energy efficiency of the energy production sectors;

(iv) estimating the energy content of imports and exports; and

(v) assessing short-term trade offs between energy use and macro-economic variables such as income and employment.

Input-output analysis is an important aid to energy planning. The general equilibrium approach is essential for a wide range of energy problems since changes in energy production and consumption often involve complex inter-sectoral effects. Using an input-output model, it is possible to examine the feasibility of reaching the policy targets of the government or to simulate the impact of new trends in technology or behaviour within the private sector. Further, different energy scenarios can be constructed delineating realistic bounds within which movements of key variables might be expected to take place (Jansen 1978).

2.2 Construction of Energy Input-Output Tables

Energy economic input-output analysis is basically an extension of Leontief input-output analysis. There are two approaches to constructing energy economic input-output tables. Both these approaches conform to the Leontief system of input-output modelling. For convenience these two approaches may be termed Approach I and Approach II. Approach I is a **hybrid** formulation of the traditional input-output table and was suggested by Bullard and Herendeen (1974a). It is discussed in Griffin (1976) Blair (1979), Dossani and Preziosi (1980), Miller and Blair (1985) and others, and has been widely used (see for example Bullard et al. 1978, Blair 1979, James 1980b, Hannon 1982, Miller and Blair 1985, Gowdy et al. 1987, and Gowdy and Miller 1987a and 1987b). Approach II was developed earlier and was widely used in 1960s and in early 1970s (Miller and Blair 1985, p. 217).

The distinction between these two approaches lies on their respective assumption on energy prices paid across the purchasing sectors in an economy. Approach I assumes that the inter-industry prices of energy of a particular type are different while Approach II considers that the price of a particular type of energy is uniform across the purchasing sectors.

2.2.1 Approach I

In this approach a set of matrices, Z^* (which incorporates energy in a flow matrix (E) measured in physical units e.g. petajoules), A^* (a direct energy requirements matrix) and $(I-A^*)^{-1}$ (a total energy requirements matrix), are constructed. These matrices are analogous to the matrices Z (the intermediate transactions quadrant), A (the direct requirements matrix) and $(I-A)^{-1}$ (the total requirements matrix) of standard input-output analysis.

Inter-industry Transaction Matrix (Z*): This hybrid matrix is formulated by taking the original inter-industry transaction matrix 'Z' and replacing the energy rows with the corresponding rows in the energy flow matrix 'E'. Thus a new transaction matrix Z* is formed where the energy rows are measured in energy units (petajoules) and the non-energy rows are in the usual monetary units (dollars). The corresponding elements of energy and non-energy sectors in the total output (X*) and final demand (Y*) vectors are expressed accordingly.

Energy Flow Matrix (E): An energy flow matrix depicts energy flows in physical units (petajoules) and is constructed as follows. Assume the economy has n sectors and m of the n sectors are energy sectors. The matrix of energy flows E, would then be of dimensions m x n. Let Ei represents the sum of values in the E matrix, that is, the total amount of energy purchased (in intermediate usage) by the n sectors of the economy. Further, assume that energy consumption as final demand is also in physical units, and is denoted by Ey. Total energy consumption in the economy, F, can then be defined as:

$$F = Ei + Ey.$$

In a two sector economy (one energy and the other non-energy), and in matrix notation, the hybrid form of the inter-industry transactions matrix (Z*) and the vectors of total output (X*) and final demand (Y*) can be expressed as follows:

$$Z^* = \begin{bmatrix} \text{Petajoules} & \text{Petajoules} \\ \$ & \$ \end{bmatrix} \qquad Y^* = \begin{bmatrix} \text{Petajoules} \\ \$ \end{bmatrix}$$

$$X^* = \begin{bmatrix} \text{Petajoules} \\ \$ \end{bmatrix}$$

Direct Requirements Matrix (A*). The elements of the matrix a^*_{ij} are calculated in a manner analogous to those elements, a_{ij}, in the usual A matrix of the standard input-output model. In the standard model, $a_{ij} = Z_{ij}/X_j$ where Z_{ij} represents the amount of intermediate input required from sector i for the production of sector j. For the direct requirements matrix, the elements are defined as $a^*_{ij} = Z^*_{ij}/X^*_j$, where Z^*_{ij} and X^*_j are elements of the Z* matrix and X* vector respectively.

$$\text{Hence, } A^* = Z^*(X^*)^{-1} = \begin{bmatrix} \dfrac{\text{Petajoules}}{\text{Petajoules}} & \dfrac{\text{Petajoules}}{\$} \\ \dfrac{\$}{\text{Petajoules}} & \dfrac{\$}{\$} \end{bmatrix}.$$

The **total requirements matrix** $(\mathbf{I-A^*})^{-1}$ can be derived following the usual procedures in obtaining the Leontief inverse $(I-A)^{-1}$ of the standard input-output model.

The elements in $(I-A^*)^{-1}$ have the same units as A^* except, of course, that these represent total requirements (petajoules or dollars) per unit (petajoules or dollars) of final demand rather than the direct requirements per unit of total output.

The extraction of energy rows from A^* and $(I-A^*)^{-1}$ can be done by constructing the matrix product $F^*(X^*)^{-1}$. F^* is constructed as follows:

$$F^* = \begin{bmatrix} F_k \\ 0 \end{bmatrix}$$

where F_k and 0 (zero) represent energy rows and non-energy rows and k denotes the number of energy sectors, respectively. Since the non-zero elements of F^* are identical to the corresponding values in X^*, the result of this product $F^*(X^*)^{-1}$, is a vector of ones and zeros, the ones denoting the location of energy sectors (Miller and Blair 1985, p. 203). The direct energy coefficients (the energy rows of A^*) and total energy coefficients (the energy rows from $(I-A^*)^{-1}$) can be extracted as follows:

Direct energy coefficient (δ) = $F^*(X^*)^{-1}A^*$ and

Total energy coefficient (α) = $F^*(X^*)^{-1}(I-A^*)^{-1}$.

Here, δ represents consumption of direct energy per dollar or petajoule of output by the non-energy and energy sectors respectively. α value means consumption of both direct and indirect energy per dollar or petajoule of output by the non-energy and energy sectors, respectively.

The essential properties of the hybrid formulation of the energy input-output problem have been illustrated with an example by Miller and Blair (1985, p. 205).

The fundamental requirement of a suitable energy input-output model is that it satisfies a set of energy conservation conditions. According to Herendeen (1974) the energy conservation condition can be stated as:

$$\alpha_{kj}X_j = \sum_{i=1}^{n} \alpha_{kj}Z_{ij} + f^*_{kj} \qquad \text{.....(1)}$$

where α_{kj} is the amount of energy required to produce a dollar's worth of sector j's output; X_j is the total dollar output of sector j; Z_{ij} is the dollar value of sector i's product consumed by sector j. The f^*_{kj} is restricted to represent only the total energy output of primary sector. That is, energy embodied in any sector's output X_j, equals the energy embodied in all that sector's input Z_{ij} ($i = 1, 2 \ldots n$) plus the primary energy input f^*_{kj}, which is non-zero for a primary energy sector. In matrix notation, the above expression can be written as:

$$\alpha \hat{X} = \alpha Z + \hat{F}^* \qquad \ldots\ldots (2)$$

From equation (2), the value of α can be obtained as:

$$\alpha = \hat{F}^* (\hat{X})^{-1} (I-A)^{-1} \qquad \ldots\ldots (3)$$

(For details, see Miller and Blair 1985, p. 207.)

In a hybrid formulation, both $\hat{X}$ and A here are replaced by corresponding values of X^* and A^*. This formulation coincides with the energy conservation condition in equations (1) and (2).

Besides its application in measuring the energy conservation condition, Approach I can further be applied to: (i) measure energy conversion efficiencies; (ii) accounting imports; (iii) commodity by industry models; (iv) net energy analysis; (v) energy cost of goods and services; (vi) study the impacts of new technologies; (vii) study the impact of energy tax; and (viii) other applications like costs versus benefits of alternative energy conservation programmes, energy consumption analysis and regional energy trade balance. (For more details, see Miller and Blair 1985, pp. 208-217.)

2.2.2 Approach II

The alternative formulation of the energy input-output table has been described and analysed in detail with examples by Miller and Blair (1985, pp. 217-22). The evidence has shown that Approach II does not conform to the energy conservation condition except when inter-industry energy prices of a particular type are uniform (Miller and Blair 1985, p. 222).

From the observation of Miller and Blair and others, it was observed that while Approach I correctly computes the total energy requirement for any arbitrary vector of final demand consistent with the energy conservation condition, Approach II yields correct results only for the base case of final demand from which the model was originally derived. Further, Approach II was satisfactory only when the energy processes were the same across all consuming sectors (including final demand) for each energy type. (For more details, see Miller and Blair 1985, pp. 220-227).

Approach I was used in this study to construct an energy input-output table for Australia. According to the Australian Bureau of Statistics and the Bureau of Agricultural and

Resource Economics, energy prices vary among users depending on the size of energy consumed of a particular type and location of the industry vis a vis the energy sources.

2.3 Energy Input-Output Studies

A good number of energy input-output studies were carried out using Approach I. Some of the important and relevant energy input-output studies done in Overseas countries and in Australia are discussed briefly in this section.

2.3.1 Energy input-output studies in overseas countries

Energy input-output analysis was pioneered by Reardon (1973), Herendeen (1974), and Hannon and his associates at the Energy Research Group, at the University of Illinois.

In the United States, the input-output methodology was applied to national energy demand analysis. By means of cumulated energy input-output coefficients, it became possible to estimate the direct and indirect energy use patterns of the economy as a function of exogenous final demands for economic commodities (Reardon 1973, Herendeen 1974).

Bullard and Hannon (1976) evaluated the reasons for total energy use change during the 1963-67 period in the United States. Reardon (1979) analysed the reasons for changes in total energy use between 1947 and 1967 in the United States. He used some of the Energy Research Group data and similar procedures.

The input-output approach was used by Lesuis and Muller (1975) to analyse the demand for oil products in the Netherlands and by Wright (1975) to determine the energy content in the British economy.

Different energy scenarios were constructed delineating realistic bounds with which the movements of the key variables might be expected to take place. Jansen (1978) constructed different energy scenarios involving trade-offs among energy use, income and employment of various forms, and environment pollution in the Netherlands.

Hannon and Blazeck (1984) calculated marginal energy intensities[1] of the United States economy by using compatible input-output tables for the period 1963, 1967 and 1972.

Gowdy et al (1987, p. 33) examined the direct and indirect energy use in the production of fourteen agricultural products for 1972 and 1977 of the United States. During these two periods energy use increased in absolute terms but decreased in terms of British Thermal Units

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1 Marginal energy intensity represents the total energy, direct and indirect required for the most recent unit change in output. This is estimated taking into account the changes in energy intensity arising from changes in input (energy and non-energy) use due to per unit changes in output (energy and non-energy) (Hannon and Blazeck 1984, p. 86).

(BTU) required per dollar of output. In further analysis they have shown that (i) a large part of the decrease in primary energy intensity is attributable to one sector, meat animals, (ii) there was a substantial increase in electricity in almost all sectors and (iii) there was an increase in the use of energy embodied in fertilizers and agricultural chemicals in the very important food grain and feed sectors.

The early adjustment of the manufacturing sector to the first energy price shock of 1973-74 was examined by Gowdy and Miller (1987a, p. 143) by using the 1972 and 1977 United States input-output tables. Important trends during the 1972-77 period were (i) a decrease in energy used per dollar of output in both primary (coal and petroleum/natural gas extraction) and the secondary use of refined petroleum and natural gas, and (ii) little overall change in electricity intensity with almost half the manufacturing industries showing an increase in electricity input-output coefficients. The chemical industry, primary metals and motor vehicles account for one third of the total manufacturing energy use.

Gowdy and Miller (1987b, p. 1387) also examined the changing pattern of energy use in the United States from 1963 to 1977. A method was developed in an attempt to isolate some of the reasons behind the observed changes . The impact of four types of technological change and two types of demand change on energy use were examined. Two types of technological changes that were of particular importance in the time period considered, were changes in the energy mix and changes due to substitution among non-energy inputs.

2.3.2 Energy input-output studies in Australia

In Australia, the pioneering work on energy economic relationship has been studied by Hawkins (1976). He surveyed the changing energy flows in the Australian economy during the postwar period for the years 1951-52, 1961-62 and 1971-72. He found that there had been substantial growth in both the gross input of energy into the Australian economy and in the final consumption of energy. Final consumption of energy was more stably related to gross domestic product than was the gross input of energy. This was due to substantial changes in the availability of the more valuable primary fuels. Measured in constant prices, final consumption of energy grew rather faster than the Gross Domestic Product and the implicit deflator of energy consumption fell relative to that of Gross Domestic Product. Past trends in energy use have been used by Hawkins to predict the future pattern of energy flows in the Australian economy.

Other comprehensive data systems for Australia are the Reference Energy Systems developed by the Energy Systems Analysis Group at the Australian Atomic Energy Commission (Essam and Maher 1977, p. 49). The Department of National Development

(1974) has also published data on the sectoral use of energy. Energy use in the manufacturing industry has been examined by Saddler and Davies (1979) and Turnovsky et al (1978).

Vincent et al (1979, p. 79) used IMPACTS ORANI 78 model to assess the short-run adjustment problems associated with the rise of domestic oil prices to import parity. They observed that the direct effect of the fuel price increase did not add much to costs. However, indirect cost increases arose from the price increases occurring in other intermediate inputs and employed labour.

Vincent et al (1980) examined the effects of higher oil prices attributable to likely continued increases in the world price of oil relative to the world prices of other internationally traded goods assuming that the domestic price is maintained at world parity. The results of the analysis suggested that increases in world crude oil prices, provided they do not impinge directly on the price of coal, would lead to an expansion in the output of the export oriented agricultural and mining sectors at the expense of the more domestically oriented manufacturing and service sectors.

Energy economic input-output tables for Australia were first developed by James (1980b). He proposed an accounting framework designed to systematize energy and economic data and provided a flexible basis for the construction of input-output models of many different kinds. The accounts contain energy make and absorption matrices which together provide a complete set of energy balances for the Australian economy, describing the production and consumption of primary and secondary energy commodities, trade in energy products and energy losses sustained by the system between production and consumption points. His paper contains a discussion of techniques of constructing input-output models with a mixture of physical and monetary coefficients. Such a model has been termed AUSTIOM (Australian input-output model).

2.4 Analytical Procedures Used in this Present Study

In this study, the sectoral changes in energy use are investigated using input-output tables. As mentioned earlier, similar types of work were undertaken by Hannon (1982), Hannon et al. (1983), Hannon and Blazeck (1984), Gowdy et al. (1987), Gowdy and Miller (1987a and 1987b). They all constructed the basic energy input output table using Approach I. However, the subsequent modification of energy input-output matrices and the manipulation of data as required were different among the researchers depending on their underlying research objectives.

The objectives of the present study are to look at the extent to which the total changes in energy use in Australia are technology induced and demand induced. As these objectives are similar to those of Gowdy and Miller (1987b), the methodological constructs developed and used by them are discussed here to help understand the approach adopted in this study.

2.4.1 Technology induced changes in energy use

Technology induced changes in energy use arise from changes in the technology of production from one period to another period. Technology of production, in the context of input-output analysis, can be defined as the amount of intermediate input or output (both energy and non-energy inputs) required to produce a given level of output by a sector in a particular time. The elements in the intermediate quadrant (traditionally called the 'A' matrix) of an input-output table represent the technology of production for a point in time. This production technology is fixed in a given period. It may change from time to time due to: (a) changes in relative prices of intermediate input or output; (b) advancement in engineering know-how; and (c) government intervention.

The input-output coefficients of a direct coefficients matrix (the A matrix) indicate direct consumption or use of intermediate products per unit of production by a particular sector. The direct use of intermediate inputs may include either energy inputs or non-energy inputs or both. With further manipulation of energy and non-energy use data, one can obtain a Leontief inverse $(I-A)^{-1}$. The coefficients of the Leontief inverse matrix indicate both direct and indirect use of intermediate products per unit of output of a sector. The difference between direct coefficient and coefficients from the Leontief inverse indicates the indirect use of intermediate products. In this way the direct, and indirect use of energy and non-energy inputs can be estimated.

In chapter 1, it was mentioned that changes in energy use arising from technological change during 1974 to 1980 consist of both direct and indirect changes. Direct changes mean changes in direct consumption of energy. The differences between the direct energy coefficients of these two periods show direct changes in energy use. However, the computation of indirect change is not straightforward. Indirect change, in other words, means induced change. Indirect change in energy usage arises, for example when a sector substitutes an input which uses relatively less (more) energy for a more (less) energy intensive input, such as the substitution of steel for aluminium (as aluminium is more energy intensive than steel). If this happens, the sector would then have made an energy saving technological change. Further, indirect change in energy use may result from substitution of one type of energy input for another. This change in energy input-mix may result from the growing importance of electricity, for example, as an intermediate input over other energy inputs. It may also happen when the relative prices of energy products encourage substitution of particular fuel type(s) for other(s).

In this study, four types of technological change have been analyzed utilizing input-output analysis. These technological changes originate from (i) changes in direct energy use (mentioned earlier); (ii) indirect change in the level of energy use, (iii) indirect change in the mix of energy inputs and (iv) indirect change in non-energy inputs. Estimation of these direct and indirect changes will be elaborated upon later.

2.4.2 Demand induced changes in energy use

As well as technology induced changes, the changes in energy use may also result from changes in final demand. It was assumed in formulating the objectives of this study that when there were increases or decreases in energy prices or when the relative prices of different final products changed, the consumer's buying pattern would change accordingly until the utilities so derived were maximized (assuming further that the consumers were utility maximizing). In the context of this study, these changes in buying patterns are reflected in changes in the share of industrial products constituting a particular final demand. Changes in the proportion of industrial products have varying impacts on the level and mix of energy use. Further, with the growth of the economy, the level of demand of individual industrial products may undergo changes. These changes in the mix of final demand for goods and services and absolute level of final demand induce changes in the requirements of energy throughout the economy.

2.4.3 Methods for estimating technology and demand induced changes in energy use

Each of the above changes in energy use (technology and demand induced) may be estimated by constructing and modifying the energy input-output matrix as required. The way the necessary modifications and subsequent analyses have been done are discussed below. First, the notation for the energy input-output matrices is redefined to avoid excessive use of superscripts in the following sections. To this end the asterisk (*) used to denote the energy input-output matrices is dropped, so that

A is the hybrid direct coefficient matrix,

Y is the hybrid final demand matrix

X is the hybrid total output vector,

E is a subset of vector X containing only the energy flows,

t and t+1 are time periods indicating 1974-75 and 1980-81 respectively.

Technology Induced Change ΔE^{TC}: To estimate the effect of different types of technological change on energy use, the level of final demand is assumed to be constant. In this study, final demand at period t, Y_t was used throughout in estimating different forms of technological changes in energy use. The change in energy use induced by technology induced change is comprised of direct and indirect changes as defined below:

Total Direct Change ΔD: Total direct change in the consumption of energy and non-energy inputs can be calculated as:

$$\Delta D = D_t - D^* \tag{1}$$

D_t and D^* represent the total amount of direct consumption of energy and non-energy by all sectors in the economy in periods t and t+1, respectively. D^t and D^* can be estimated as

$$D_t = A_t Y_t \tag{2}$$

$$D^* = A_{t+1} Y_t \tag{3}$$

1. **Change in direct energy requirement, ΔE^d**: It is estimated as follows:

$$\Delta E^d = E_t^d - E^* \tag{4}$$

where E_t^d and E^* are subsets of D_t and D^* respectively. E_t^d and E^{d*} represent direct total energy consumption of a particular fuel type(s) in periods t and t+1, respectively, by all sectors in the economy. The difference ΔE^d indicates changes in total direct energy requirements of output produced in all sectors in period t+1 assuming t period final demand (Y_t).

Further, the change in direct energy requirements per unit of output may be estimated as the difference between the direct energy coefficients of periods t and t+1 of respective sectors (energy and non-energy) assuming the final demand is constant at Y_t. In this study, the total change in direct energy requirements of a fuel type has been calculated as follows:

$$\Delta E_j^d = (a_{ij}^t - a_{ij}^{t+1}) Y_i^t \tag{5}$$

where i stands for energy and non-energy sectors,
j stands for energy commodities (fuel type) only, and
a_{ij} is the direct energy coefficient of sector i for fuel type j.

Here, ΔE_j^d denotes changes in direct energy requirement in all sectors in the economy for a particular energy type j. In matrix notation ΔE_j^d is written in ΔE^d. However, the changes in direct energy requirement of a particular sector for a particular fuel type during the periods t and t+1 can be calculated using the above formula.

2. **Total Indirect Change:** It has been mentioned earlier that the total indirect change in energy use consists of: (i) changes in the level of energy use, (ii) changes in energy mix, (iii) and changes in non-energy input mix.

(i) **Indirect change in the level of energy, ΔE^{lc}:** This is a measure of the indirect change in energy embodied in direct inputs. Such a change results from increases or decreases in the energy coefficients of the direct inputs, assuming no change in direct input mix. To calculate the indirect change in the level of energy consumption, matrix A as mentioned earlier, has been modified into A* as follows. First, all the non-energy direct coefficients are from t period, second, the energy coefficients have the mix of t period, that is, the proportion of different types of energy used is of t period, third, the level of direct energy usage is that of t+1 period.[2] Then, the following steps are followed.

$$X^* = (I-A^*)^{-1} Y_t \tag{6}$$

$$\Delta E^* = E_t - E^* \tag{7}$$

$$\Delta E^{lc} = \Delta E^* - \Delta E^d \tag{8}$$

where E^* is a subset of X^* and ΔE^d denotes change in direct energy requirement. E_t and E^* indicate direct and indirect energy use in period t and under the new arrangements (when non-energy coefficients are from t period and energy coefficients have t mixes but t+1 level, respectively). ΔE^* represents the total direct and indirect change in the level of energy use. As ΔE^d indicates direct change in energy use, the difference, ΔE^{lc} indicates indirect change in the level of energy use.

For individual sectors, the indirect change in the level of energy consumption has been calculated in the following manner:

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2 For example, assume agricultural sector consumed directly a total of 300 petajoules of energy in period t which includes 150 petajoules from electricity and 150 petajoules from gas utilities. This indicates the proportion or share of electricity and gas to total energy usage was 0.50 each for the sector. In period t+1, further assume that agricultural sector consumes 400 petajoules of energy including 120 petajoules from gas and 280 petajoules from electricity. Now, to obtain energy rows in the transaction matrix A*, the total energy use in t+1 period, that is 400 petajoules was multiplied by the proportion of electricity and gas consumed in t period. This gives the use of electricity and gas at 200 petajoules each in t+1 period. The total becomes 400 petajoules. In A* matrix, the energy coefficients, thus have t mixes (proportion) but t+1 level.

$$\Delta E_j^{lc} = (r_{ij}^t - r_{ij}^*)\, Y_i^t - (a_{ij}^t - a_{ij}^{t+1})Y_i^t \tag{9}$$

= (direct plus indirect change in the level of energy consumption) – (direct change in the level of energy consumption as calculated in equation 5).

= indirect change in the level of energy consumption.

In the above, r_{ij} represents direct and indirect energy coefficients of sector i for fuel type j. The r_{ij} and r_{ij}^* values are obtained from the $(I-A)^{-1}$ and $(I-A^*)^{-1}$ matrices, respectively. a_{ij} is the direct energy coefficient of sector i for fuel type j. Hence, ΔE_j^{lc} represents the total indirect change in the level of energy consumption of fuel j in the economy during periods t and t+1. Using the above formula, the indirect change in the level of energy consumption for individual sectors has been calculated.

(ii) **Indirect change in the mix of energy use, ΔE^{em}:** To calculate the indirect change in the mix of energy use, the previously constructed matrix A*, has further been reconstructed as A**. In this time, the non-energy coefficients are from period t, energy coefficients (both mix and level) are from period t+1. Now, matrices A* and A** have the same non-energy coefficients from period t, have the same level in energy coefficients but they differ only in energy mixes. Thus, the changes in energy use (E** – E*) are due to changes in energy mix.

Indirect change in the mix of energy use has thus been calculated as:

$$\Delta E^{em} = E^{**} - E^{*} \tag{10}$$

$$X^{**} = (I-A^{**})^{-1}Y_t \tag{11}$$

where E** is a subset of X**.

For a particular sector, the indirect change in the mix of energy use of a fuel type has been estimated as:

$$\Delta E_j^{em} = (r_{ij}^{**} - r_{ij}^{*})Y_i^t \tag{12}$$

where r_{ij}^{**} values are obtained from the $(I-A^{**})^{-1}$ matrix.

(iii) **Indirect change in the non-energy input mix, ΔE^{ne}:** To calculate this, first, the matrix A** has again been modified by replacing the non-energy coefficients of t period by those of t+1 period. The A** matrix and its modified form equivalent to A_{t+1}, have now the same energy coefficients (both mixes and level) but they differ only in non-energy input coefficients. Thus, the differences in energy use E*** – E** as shown below are due to substitution of non-energy inputs in the t+1 period (when energy mixes and energy level remain constant).

Now, the indirect change in energy use due to changes in non-energy input mix has been calculated as

$$\Delta E^{ne} = E^{***} - E^{**} \tag{13}$$

$$X^{***} = (I - A_{t+1})^{-1} Y_t \tag{14}$$

where E*** is a subset of X***.

Indirect change in non-energy input mix for individual sectors has been estimated as:

$$\Delta E_j^{ne} = (r_{ij}^{***} - r_{ij}^{**}) Y_i^t \tag{15}$$

where r_{ij}^{***} values are obtained from the $(I-A_{t+1})^{-1}$ matrix.

Thus, the total change in energy use due to technological change, ΔE^{TC} is:

$$\Delta E^{TC} = \underbrace{\Delta E^{d}}_{\text{direct change}} + \underbrace{\Delta E^{lc} + \Delta E^{em} + \Delta E^{ne}}_{\text{indirect change}} \tag{16}$$

Demand Induced Change, ΔE^{DC}: Further, changes in direct and indirect energy use due to changes in the final demand pattern have been calculated. To estimate these changes, the technology of production of period t+1 has been used throughout the estimation of different forms of demand induced (changes in demand mix and changes in the level of demand) changes in energy use.

Changes in demand mix, ΔE^{dm}: This is a measure of the extent to which the final consumers changed their buying patterns, so that the bundle of goods and services purchased were more or less energy intensive. To estimate the demand induced changes, especially the demand mix, some modifications of the final demand vector 'Y' have been carried out. A new final demand vector (Y′) is constructed where the proportion of industrial products constituting final demand is identical to the proportion consumed in t+1 period, but the sum of the industrial products is equal to those of t period.[3] Technology of production used to estimate the direct and indirect energy use remains the same at period t+1.

Changes in energy use due to changes in demand mix can be estimated as:

$$\Delta E^{dm} = E' - E^{***} \tag{17}$$

$$X' = (I - A_{t+1})^{-1} Y' \tag{18}$$

where E′ is a subset of X′. The differences in energy use, ΔE^{dm} thus, are due to changes in demand mix. For a specific sector, the demand mix induced changes in energy use has been calculated using the following formula:

$$\Delta E_j^{dm} = (r'_{ij} - r^{***}_{ij}) Y'_i \tag{19}$$

where r'_{ij} values are obtained from the $(I - A_{t+1})^{-1}$ matrix.

Changes in the level of final demand ΔE^{ld}: Here, the changes in energy use is calculated as follows:

$$\Delta E^{ld} = E_{t+1} - E' \tag{20}$$

$$X_{t+1} = (I - A_{t+1})^{-1} Y_{t+1} \tag{21}$$

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[3] Assume an economy consumes or uses a total of \$80 worth of output as final demand in t+1 period. This may include consumption of output of \$20 from agricultural sector, \$20 from manufacturing sector and \$40 from service sector. This indicates the proportion of final demand consumed in t+1 period in above sectors are 0.25, 0.25 and 0.50 respectively. Further, assume that the economy consumes in period t a total of \$50 output as final demand. This may include \$10 of output from agricultural sector, \$20 from manufacturing sector and \$20 from service sector. To derive a final demand vector Y′, the total final demand of t period has been multiplied by the proportions of final demand consumed in t+1 period. In this example, the corresponding elements in vector Y′ for agricultural, manufacturing and service sectors are \$12.5, \$12.5, and \$25 respectively. The sum of these equal to \$50 at t period.

where E_{t+1} is a subset of X_{t+1}.

Both E_{t+1} and E' indicate total direct and indirect energy use of all sectors. The final demand vectors Y' and Y_{t+1} have the same industrial mix but they differ only in the level. In the above, the difference in energy use E_{t+1} - E', hence, is due to changes in the level of final demand. In this case, the change in energy use in a particular sector has been calculated as:

$$\Delta E_j^{ld} = (r_{ij}^{t+1} - r_{ij}')Y_{t+1} \qquad (22)$$

where r_{ij}^{t+1} values are obtained from the $(I - A_{t+1})^{-1}$ matrix.

Thus, the total change in energy use as a result of demand change is , ΔE^{DC}:

$$\Delta E^{DC} = \Delta E^{dm} + \Delta E^{ld} \qquad (23)$$

Hence, total changes in energy use, ΔE^{Tot}:

$$\Delta E^{Tot} = \Delta E^{d} + \Delta E^{lc} + \Delta E^{em} + \Delta E^{ne} + \Delta E^{dm} + \Delta E^{ld}$$

2.5 Limitations of Energy Input-output Analysis

Input-output analysis, despite its usefulness suffers from shortcomings and uncertainties. Those relevant to this study are mentioned below.

(1) Input-output data are subject to inaccuracies from: (i) lack of complete coverage of an industry; (ii) restriction of information for proprietary reasons; and (iii) use of different time periods for different kinds of data. Errors in the direct coefficients matrix, A, may generate disproportionate errors in the inverse matrix, $(I-A)^{-1}$ (Herendeen 1973, p. 7).

(2) Price level changes over time. Due to inflation, price levels change while physical quantities may not. Changes in price levels can be approximately corrected by using deflators (as has been done in this study). Deflators are sometimes inaccurate and may not conform to Australian Bureau of Statistics' sector definitions. Measuring quantities in terms of constant 1974-75 dollars is a surrogate for using physical units. For some

products the correspondence between physical units and 1974-75 dollars is known and for others it is not.

(3) The use of dollars rather than physical units to express physical dependencies is risky. For example, aggregation can combine two processes whose energy intensities differ widely in the same sector. Further, dollar economies of scale may be implicit in the a_{ij}, whereas there would be no (or little) corresponding effect in physical terms (Herendeen 1973, p. 7).

2.6 Data Sources

The 1974-75 and 1980-81 national input-output tables for Australia were used to compare the immediately after and post oil crises situations respectively. Due to non-availability of energy data by sector, the input-output table for 1968-69 could not be used to represent the pre-oil price shock situation. The input-output table for 1974-75 was chosen because this was the next available. This was thought reasonable as it is unlikely that much of the structural adjustment induced by the 1973-74 oil price shock had occurred by 1974-75. Similarly, it is recognized that not all the adjustments induced by the 1978-79 oil price shock would have occurred by 1980-81 and be reflected in that year's national input-output table.

Basic input-output data were obtained from the Australian Bureau of Statistics (1981a and 1987a). Energy use data (in physical units) were taken from 'Energy Demand and Supply, Australia 1960-61 to 1984-85' published by the Department of Resources and Energy (1987). Several requests were made to the Australian Bureau of Statistics and the Department of Resources and Energy for unpublished data. This included information on disaggregation of the coal, oil and gas sector, petroleum products nec from the petroleum and coal products sector.

To overcome the problem of inflation embodied in the 1980-81 input-output table and to make this table comparable to that of 1974-75, the input-output table of 1980-81 was deflated by a set of reindexed price deflators for respective sectors and in some cases by implicit price deflators, when no such price deflators were available (this is discussed further in chapter 3). These deflators were calculated from the price indexes published in the Australian Bureau of Statistics (1975a, 1978a, 1978b, 1981c, 1981d, 1981e, 1982b and 1982c), wage rates published in the Australian Bureau of Statistics (1975b and 1980) and the implicit price deflators from the Australian Bureau of Statistics (1982a and 1984).

Once the energy input-output tables were constructed, further manipulations of data and matrices were done as per earlier methodological constructs developed in section 2.5.3. The computer package GRIMP (West 1986) was used to manipulate and analyse the data.

Chapter 3

CONSTRUCTION OF ENERGY INPUT-OUTPUT TABLES FOR AUSTRALIA

In the last chapter, the input-output analysis and its application in energy studies, the approaches used in the construction of energy input-output tables, and the methodological constructs used in this study were discussed. In this chapter, an interpretation of some basic concepts such as energy consumption, energy intensity and their measurements, are introduced together with the details of the energy units used in this study. The construction of an energy make matrix, an energy absorption matrix, an energy flow matrix is then discussed followed by details of the construction of an energy input-output table for Australia. The energy input-output tables are constructed with a view to subsequent use of the analytical procedures discussed earlier for the estimation of changes in energy use.

3.1 Energy Types, Energy Consumption and Energy Intensity

The concepts of energy type, consumption and intensity have been defined in this study according to the definitions of the Department of Resources and Energy (1987). There, energy types are discussed as primary energy such as coal, crude oil, natural gas, and renewables or products of their conversion, such as petroleum products, thermal electricity and town gas. Some of these derived energy forms are not consumed as fuel but are consumed in non-fuel applications e.g. lubricants, explosives, aerosol propellants, and petro-chemical feed stock. These usages have been considered in this study as their exclusion would lead to an understatement of the consumption of their primary source. For example, around 10 percent of total petroleum products are consumed in non-fuel uses, and to exclude this usage would mean a major understatement in Australian petroleum consumption and hence crude oil demand (Department of Resources and Energy 1987, p. 25).

Renewable energy types include fuel wood, hydro-electricity and solar energy. Due to problems involved in the practicability of measuring the solar input to activities such as solar salt drying, outside laundry drying, passive building heating and in the extreme case, crop growing, the measure of solar energy contribution was limited to energy input from active energy collection systems. This includes the contribution of domestic solar hot water heaters.

In subsequent analyses, especially in constructing the energy make matrix and energy absorption matrix, energy usage has been shown consisting of primary and secondary, or derived energy sources. Detailed discussion of different types of energy sources and their classification is provided in Appendix I.

3.1.1 Total energy consumption (TEC)

According to Department of Resources and Energy (1987, p. 26), total energy consumption is defined as the total quantity of primary and derived fuels consumed, less the quantity of derived fuels produced. If a derived fuel is exported from Australia, only the energy losses in its production are included in total energy consumption. For example, if coke is exported from Australia, then only the energy consumed in its production is included in Australian energy consumption. In this case, it is equal to the energy content of the coal consumed less the energy content of the exported coke. However, if the coke was consumed in Australia, its energy content, as well as the energy content in its production would be included in total energy consumption. Where a derived fuel is imported and consumed, its energy content is included in total energy consumption.

In a similar way, energy consumption of an industry or a sector is equal to the energy content of its primary and derived fuel inputs minus the energy content of any fuel it may transfer to other sectors. That is, energy input minus energy output equals energy consumption. For example, if the energy content of inputs used in the mining sector was 35 petajoules, and if the mining sector produced derived fuels of 20 petajoules, the mining sector's energy consumption would be (35 - 20 =) 15 petajoules. Accordingly, the sum of energy consumption of all sectors, including the conversion sectors (such as electricity generation, oil refining), is equal to total energy consumption of the economy.

It may be mentioned that a large proportion of primary fuels are converted into derived fuels, such as electricity and petroleum products, which are more suitable for direct consumption in end use devices. The total amount of energy consumed in non-conversion sector end use devices is called total final energy consumption (TFC). This is defined as follows:

$$TFC = ECDF - L$$

where TFC is the total amount of final energy consumption

ECDF is the amount of energy consumed to produce a derived fuel

L is the loss of energy in the production of a derived fuel.

3.1.2 Energy intensity

In this study energy intensity has been measured as the total amount of energy consumed, directly and indirectly, divided by the Gross Domestic Product measured in constant dollar terms. Data on direct energy use by sector were available (Department of Resources and Energy 1987, Table H1, pp. 99-120). Indirect energy use will be estimated by using input-output analysis. This will be discussed in more detail in chapter 4.

3.1.3 Energy units

The unit of energy measures used in this study is joule. When converting individual types of fuel from volume or weight to energy equivalence or vice versa, the factors like variation in the quantity of any fuel with time, location, temperature are kept in mind. A joule is a measure of the gross energy content of a fuel indicated by the total amount of heat that will be released by combustion. Commonly used measures are multiples of joules:

(i) Megajoules (MJ) = 10^6 J,

(ii) Gigajoules (GJ) = 10^9 J,

(iii) Petajoules (PJ) = 10^{15} J.

3.2 Construction of Energy Matrices

In this section, the construction of three sets of matrices, energy make matrices, energy absorption matrices, and energy flow matrices for the periods 1974-75 and 1980-81 are discussed. These matrices are used ultimately for the compilation of energy input-output tables for Australia for the above periods.

3.2.1 Energy make matrix

To construct an energy make matrix, five energy sectors were identified as producers of 28 energy products. The classification of 28 energy products into five major energy types is shown in Appendix 2. In conformity with the Australian Standard Industrial Classification, the five energy sectors were identified as: coal, oil and gas, refined petroleum products, electricity, and gas. There were some non-energy sectors, namely basic metal products, basic chemicals, food beverages, wood and wood products, paper and paper products, which did produce some amounts of derived energy products, although the production levels were relatively small. These production values were allocated to an energy sector which, for example, was the major producer(s) of a particular energy product(s).

Two energy make matrices (one for 1974-75 and the other for 1980-81) were constructed using the production figures of primary and derived fuels obtained from the Department of Resources and Energy (1987). For derived fuels, the production figures were provided in physical amounts, both weight and volume. These physical units were converted into energy equivalence by using the indicative energy conversion factors (Department of Resources and Energy 1987, pp. 224-226). Fuels like petroleum products not elsewhere classified and other petroleum products did not have specific conversion factors. In these cases, the averages of the relevant energy components have been used as proxy to convert the physical amount into energy equivalence. Energy imports have been allocated among the energy types on an indirect basis. That is, energy imports being allocated on a competing basis. As an illustration, an aggregated (nine energy types and five energy sectors) energy make matrix is shown in Table 3.1 for the period 1974-75 (p. 31). A particular row of the above table indicates production of different fuel types by an energy producing sector while a column represents production of a fuel type by different energy producing sectors. The column total of a fuel type provides the total supply of energy of that fuel type which is obtained from summation of domestic energy production (the commodity totals) and competing energy imports. The row summation represents the industry total of energy production irrespective of fuel types by an energy sector. Detailed energy make matrices for the periods 1974-75 and 1980-81 are shown in Appendices 3 and 4. The energy production and supply data obtained from these detailed make matrices are ultimately used in energy absorption matrix, energy flow matrix and energy input-output table.

3.2.2 Energy absorption matrix

In an energy absorption matrix, the energy types are shown in rows and industries or sectors in columns. Each column of this matrix represents consumption or absorption of total energy by a particular sector. Energy absorption or consumption of an industry was defined in an earlier section as the energy content of its primary and derived fuel inputs minus the energy content of any fuel it may transfer to other sectors. This measurement can best be illustrated with an example.

Consider the refined petroleum products sector which simultaneously consumes energy for production as an input and produces derived fuel for sale to other sectors. The amount of energy required for production and the amount of derived fuel produced for this sector in 1980 are detailed in Table 3.2.

The actual amount of energy consumed by the refined petroleum products sector has been estimated as the amount of total energy consumed minus the amount of derived energy produced. That is (128200 - 112590 =) 15610 x 10^{13} joules is the actual energy consumption by

Table 3.1

An Aggregate Energy Make Matrix, Australia 1974-75 (In 10^{13} joules)

Energy producing sectors / Energy type	Coal & Uranium	Wood & Bagasse	Coal Prod.	Crude oil and LPG	Nat. gas	Pet. prod	Non-fuel use	Town gas	Elect.	Industry Total
Coal	168390	14930							1240	**184560**
Oil & gas				52080	18920				10	**71010**
Ref.pet.prod.			28640	39280		114490	4510	370	800	**188090**
Gas								1630		**1630**
Electricity									57320	**57320**
Commodity total	168390	14930	28640	91360	18920	114490	4510	2000	59370	**502610**
Competing energy im.				39360		16080	270			**55710**
Total Energy Supply	**168390**	**14930**	**28640**	**130720**	**18920**	**130570**	**4780**	**2000**	**59370**	**558320**

Table 3.2

Energy Consumption and Derived Energy Produced by Refined Petroleum Products Sector 1980-81 (In 10^{13} joules).

Energy Consumption		Derived Energy Production	
Type	Amount	Type	Amount
Crude oil	126170	Liquified Petroleum Gas (LPG)	1910
Natural gas	910	Automotive Diesel fuel (ADO)	29360
Coal by-products	330	Industrial diesel fuel (IDF)	3350
Brown coal briquettes	330	Fuel oil	14610
Electricity	280	Petroleum products nec	2850
Solvents	110	Auto-gasoline (leaded)	49630
Bitumen	70	Lighting kerosine	570
		Aviation gasoline	350
		Aviation turbine	8460
		Power kerosine	70
		Heating oil	1010
		Lubricants, greases	420
Total:	128200	Total:	112590

(Source: Department of Resources and Energy, Table H1, page 105).

this sector. Similar procedures were followed to arrive at the actual energy consumption for all other sectors.

Energy absorption matrices were constructed for the periods 1974-75 and 1980-81. Data on energy use by sector and fuel type from the Department of Resources and Energy (1987, Table H1, pp. 99-120) were used to construct the energy absorption matrices. It may be mentioned that the energy use data were available only for 29 sectors of the economy. Accordingly, the 109 sectors in the national input-output tables were aggregated into 29 sectors, as per the Australian Standard Industrial Classification (ASIC). The aggregation scheme is provided in Appendix 5.

In the absorption matrices, the flows of 28 energy commodities measured in 10^{13} joules, into the 29 sectors (24 non-energy and 5 energy) of the Australian economy, as well as to the various final demand categories, are recorded. Imports are included and have been allocated on an indirect basis as discussed earlier. From an energy absorption matrix, one can distinguish the energy inputs that are primary to the system and those which are secondary products. For convenience, 29 sectors are aggregated into 12 sectors consisting of 5 energy sectors and 7 non-energy sectors. This aggregation is also made according to the ASIC as far as possible. The aggregation scheme is provided in Appendix 6. An aggregated energy absorption matrix (10 energy commodities, 12 sectors) for the period 1974-75 is presented in Table 3.3 for an illustration. The detailed energy absorption matrices for 1974-75 and 1980-81 are provided in Appendices 7 and 8.

It is apparent from the above absorption matrix that the amount of derived energy produced by fuel type is shown as a negative value for the obvious reasons that the column total provides actual energy consumption by a sector. For a secondary or derived fuel, a particular value in a column represents actual energy consumption of the fuel type and is measured as the amount of energy consumed of that fuel type as energy input minus the amount of the same energy type being produced. The residual value of fuel use may either be positive or negative depending on its relative size of energy production and consumption. For example, if the refined petroleum products sector consumed 350 x 10^{13} joules of automotive diesel oil and produced 460 x 10^{13} joules of automotive diesel oil, then the sector's actual energy consumption would be ({350 - 460} x 10^{13} =) - 110 x 10^{13} joules. These (-)110 x 10^{13} joules would be shown against automotive diesel oil under the refined petroleum products sector. In a similar way, the actual consumption of all other secondary fuels has been estimated.

Row summation of an absorption matrix provides total energy consumption of a fuel type which may include total intermediate use, household use and changes in stocks. In the energy absorption matrix, the energy exports have not been considered in the total Australian energy consumption although consumption of energy in production of energy exports is included. While summing up the row of a derived fuel to get its total intermediate usage, sometimes the negative energy values outweigh the positive values of the same fuel type, thus the resultant value is either positive or negative. This is evident in the total intermediate energy usage of different secondary fuels. Hence the total intermediate usage of all secondary fuel has been found to be either negative or very negligible (Table 3.3, Appendices 7 and 8). This implies that the total intermediate energy consumption in Australia (obtained from the summation of total consumption of primary and secondary energy), reflects only the consumption of primary energy input. However, sectoral energy consumption (column totals) includes both primary and secondary or derived energy. This is also evident in Table 3.3 and Appendices 7 and 8.

Table 3.3

An Aggregate Energy Absorption Matrix, Australia 1974-75 (In 10^{13} joules)

Fuel type \ Sectors	Agr.	O.Min	Coal	Oil & Gas	Mfg.	Ref. pet. prod.	Metal & M.Prod.	Elec.	Gas	Const.	Trans. & Comm.
A. Primary energy											
Coal & uranium		2610	30		2410		30960	61490	180	120	30
Crude oil					-740	123190					
Wood, Bagasse etc.					7280		250	150			
Nat.gas		50		1710	2930	150	6220	3430	810	20	30
SUB TOTAL(A):		2660	30	1710	11880	123340	37430	65070	990	140	60
B.Secondary energy:											
Coal prod.		-2440			1010	660	-1140	380	-50		
Pet. prod. except non-fuel applications	3540	2460	360	130	10920	-107840	13200	4830	1840	2950	69820
Town gas					130		280		-1440		
Electricity	380	1240	350	30	2350	230	4880	-16350	10	260	370
Non-fuel applications						10					
SUBTOTAL(B):	3920	1260	710	160	14410	-106950	17220	-11140	360	3210	70190
TOTAL ENERGY USAGE:	3920	3920	740	1870	26290	16400	54650	53930	1350	3350	70250

Fuel type \ Sectors	Serv.	Total Inter. Usage	House hold	Export	Change in Stocks	Aust. Energy Cons.
A. Primary energy						
Coal & uranium	520	93350	90	95030	410	98850
Crude oil		12240			-2790	119660
Wood, Bagasse etc.	110	7790	7150		-10	14930
Nat.gas	740	16090	2820		-10	18920
SUB TOTAL(A):	1370	244680	10060	95030	-2380	252360
B.Secondary energy:						
Coal prod.	190	-1390	690	1140	-30	-730
Pet. prod. except non-fuel applications	2830	4770	5180	12730	2430	12380
Town gas	300	-730	730			
Electricity	3440	-2540	7960		20	5440
Non-fuel applications		10				10
SUBTOTAL(B):	6760	120	14560	13870	2420	17100
TOTAL ENERGY USAGE:	8130	244800	24620	108900	40	269460

Despite the availability of data on energy consumption by fuel type and industry, there were some problems in compiling the absorption matrices. Data on energy consumed or derived energy produced of a particular type(s) by an industry or a sector were not usually shown explicitly. Rather, the consumption and production figures of a fuel type by an industry were included in the total energy consumption and production figures of that industry. In this case, monetary information on energy consumption and production of a particular sector obtained from the input-output tables (commodity details) and in some instances the national input-output tables were used to apportion the energy content of a fuel type from the total energy consumption and production. In some instances help from the Australian Bureau of Agricultural and Resource Economics was sought and subjective judgement had to be used to resolve such problems.

3.2.3 Energy flow matrix

Industry by industry energy flow matrices of dimensions 5 x 29 were constructed for the periods 1974-75 and 1980-81. These matrices are basically the summarized version of the energy absorption matrices with the total energy demand and supply excluded in the latter.

An aggregated version of the energy flow matrix (dimensions 5 x 12) for the period 1974-75 is shown in Table 3.4. The detailed energy flow matrices are provided in Appendices 9 and 10. These flow matrices have been used to construct an energy input-output table for Australia. The construction procedures for the energy input-output table are discussed in the next section.

3.3 Construction of Energy Input-Output Table

3.3.1 Construction of the table

The essence of an energy input-output table is that the energy flows are in physical units and the non-energy flows are in monetary values. The energy flow matrix was constructed with five energy types i.e. coal, crude oil and gas, refined petroleum products, electricity, and gas utilities with the objective of incorporating these energy flow data into the basic input-output tables for Australia. In transplanting these data into national input-output tables, it was observed that except for the electricity and gas utility sectors, all other energy sectors were in aggregated form. Coal, oil and gas are treated as one sector (sector 12.00) in the National Input-Output Table. In a similar way, petroleum and coal products are treated as one sector (sector 27.08). In this study these sectors have been disaggregated as described below.

Table 3.4

An Aggregate Energy Flow Matrix, Australia, 1974-75 (In 10^{13} joules)

Energy types \ Sectors	Coal	Oil & Gas	Ref. pet. prod.	Elect.	Gas	All energy sectors	Agr.	O.Min	Misc. Mfg.	Metal & min. prod.
Coal	30		660	45670	130	46490		170	10700	30070
Crude oil		1720	15480	3430	1100	21730	20	60	2610	6670
Ref.pet.prod.	360	120	30	4830	110	5450	3520	2450	10500	12480
Elec.	350	30	230		10	620	380	1240	2350	5150
Gas									130	280
Total Int. Use	740	1870	16400	53930	1350	74290	3920	3920	26290	54650
Primary energy inputs	211220	108410	102600	5440	650	428300				
Australian energy prod.	211960	110280	119000	59370	2000	502590				
Competing energy imp.		39360	16350			55710				
Total Energy Supply	211960	149640	135350	59370	2000	558320				

Energy types \ Sectors	Const.	Trans. & comm.	Services	Total Int. Demand	House hold	Export	Changes in Stock	Bal. of items	Final demand	Total demand
Coal	150	30	790	88400	7920	96170	2720	16750	123560	**211960**
Crude oil	490	130	590	32300	3300	5340	2390	1063	117340	**149640**
Ref.pet.prod.	4060	69720	1400	109580	4700	7390	-80	13760	25750	**135350**
Elec.	1420	370	2280	13810	7970 -	-		37590	45560	**59370**
Gas	180 -		120	710	730 -	-		560	1290	**2000**
Total Int. Use	6300	70250	5180	244800	24620	108900	5030	174970	313520	558320
Primary energy inputs										
Australian energy prod.										
Competing energy imp.										
Total Energy Supply										

The Australian Bureau of Statistics was requested to furnish disaggregated data on these aggregated energy sectors. The Bureau could not provide such information at the disaggregated level of intermediate non-energy input usage by coal, crude oil and gas sectors. The only available information was on total intermediate usage by coal, and crude oil and gas sectors. Using the total values, each non-energy component of intermediate input usage was apportioned between the coal, and crude oil and gas sectors. For energy components of intermediate input use, the data were available from the energy flow matrix. It may be mentioned that the gas component in the oil and gas sector could not be isolated, because the Australian Standard Industrial Classification did not permit such disaggregation. Also, the coal products nec (not elsewhere classified) portion of petroleum and coal products sector (sector 27.08) could not be isolated and transferred to the coal sector as hoped. However, because coal products nec constitute only 0.9 per cent of the petroleum and coal products sector (Australian Bureau of Statistics 1981b, and 1987b, Table 2) any resultant error was thought to be insignificant. For convenience, the petroleum and coal products sector was renamed refined petroleum products in the energy input-output table.

After making the necessary disaggregation of energy sectors, the dollar values of energy flows in the standard input-output table were replaced by the data obtained from the energy flow matrix. Further, the dollar values of energy production, import and total supply figures of the different energy sectors were replaced by data from the energy make matrix and the energy flow matrix. Thus, the feature of the energy input-output table is that the energy flows are in energy units and the non-energy flows are in monetary units. Hence, the row and column totals of any sector in an energy input-output table are not equal. To make the row and column totals equal for subsequent analyses, necessary adjustments were made in the primary input quadrant. These adjustments, however, did not in any way affect the analyses and results of the study.

The energy input-output tables of dimensions 29 x 29 for the periods 1974-75 and 1980-81 as constructed are shown in Appendices 11 and 12 and an aggregated table of dimensions 12 x 12 is provided in Table 3.5 for the period 1974-75. The energy flows in Table 3.5 from the five energy sectors, coal, oil and gas, refined petroleum products, electricity and gas, among 12 sectors (5 energy, 7 non-energy) are in 10^{13} joules (obtained from the energy flow matrix, Table 3.4) while the non-energy flows are in million dollars (obtained from the national I-O tables).

3.3.2 Deflation of 1980-81 national input-output table to 1974-75 values

Any national input-output table, with several assumptions can form the basis of an economy wide general equilibrium model that focuses on production (Dervis et al. 1982, p. 21). The values in the 1974-75 national input-output table are nominal in current prices. To

Table 3.5

An Aggregate Energy Input-Output Table, Australia 1974-75

Sector	agril.	o.min	oil&gas	coal	manf.	ref.pet	met.&me	elec.	gas	constr.	trans.&
agril.	479	0	1	8	2459	0	13	4		13	7
o.min	0	280	8	74	17	10	802	0	0	92	9
oil&gas	20	60	1720		2610	15480	6670	3430	1100	490	130
coal		170		30	10700	660	30070	45670	130	150	30
manf.	290	27	5	8	2993	40	510	0	0	747	50
ref.pet	3520	2450	120	360	10500	30	12480	4830	110	4060	69720
met.&me	59	156	10	57	555	58	6361	18	2	1916	672
elec.	380	1240	30	350	2350	230	5150		10	1420	370
gas	0	0	0		131	0	280			180	
constr.	277	78	5	24	1203	66	882	37	7	1170	725
trans.&	187	109	5	27	544	44	582	26	8	561	191
service	36	83	4	14	122	2	110	6	0	512	78
TOTAL I	5248	4654	1908	952	34182	16620	63909	54021	1368	11313	71983
H-Hold	758	582	15	339	4910	83	6911	536	69	8872	3886
P 2	-601	-3262	147714	210587	-24364	117899	-52369	4671	530	-1197	-68420
Imports	640	211	2	82	4631	749	3933	142	34	5377	1908
TOTAL P	797	-2468	147732	211008	-14822	118730	-41526	5349	634	13053	-62626
TOTAL	6045	2185	149640	211960	19360	135350	22384	59370	2001	24365	9357
Employ.	380234	54614	3541	30838	522707	6027	585944	75079	9348	1432654	555865

Sector	service	TOTAL I	H-Hold	O.F.D.	Exports	TOTAL F	TOTAL
agril.	13	2997	626	638	1784	3048	6045
o.min	6	1300	2	52	832	886	2185
oil&gas	590	32300	3300	108700	5340	117340	149640
coal	790	88400	7920	19470	96170	123560	211960
manf.	1993	6663	8253	2545	1899	12697	19360
ref.pet	1400	109580	4700	13680	7390	25770	135350
met.&me	342	10205	2870	7441	1868	12179	22384
elec.	2280	13810	7970	37590		45560	59370
gas	120	711	730	560		1290	2001
constr.	1035	5509	7511	10869	476	18856	24365
trans.&	1739	4022	2880	935	1520	5335	9357
service	4845	5813	11775	16019	171	27965	33779
TOTAL I	15153	281310	58537	218498	117450	394485	675795
H-Hold	14057	41020					41020
P 2	7	331195	-23759	-178733	-108047	-310539	20656
Imports	4562	22270					22270
TOTAL P	18626	394485	-23759	-178733	-108047	-310539	83946
TOTAL	33779	675795	34778	39765	9403	83946	759742
Employ.	2153480	5910331					

NB. The energy flows are in 10^{13} joules, the non-energy flows are in million dollars.

1 Here, the row and column totals of individual sectors have been equalised by adjustment in the primary input quadrant (especially in row P2).

move from the nominal input-output accounts to a real model, we must first separate prices and quantities in the accounts. Ignoring exports and imports, the nominal input-output accounts can be written as:

$$P_iX_i = \sum_{j=1}^{n} P_iZ_{ij} + P_iY_i \qquad .....(1)$$

where P_i is the price of output in sector i

X_i is the production in sector i,

Z_{ij} is the flow of intermediate goods for sector i to sector j, and

Y_i is the final demand for sector i.

Assuming a fixed coefficient technology, the input-output coefficients are constant and are given by:

$$a_{ij} = \frac{Z_{ij}}{Z_j} \qquad .....(2)$$

In any given year, e.g. 1974-75, in a national input-output table, the ratio of nominal intermediate flows to nominal output is given by:

$$\frac{P_ia_{ij}}{P_j} = \frac{P_iZ_{ij}}{P_jZ_j} \qquad .....(3)$$

Now, given a base year national input-output table (1974-75), it is convenient to define the units of real flows such that all prices equal one. In this situation, equations (2) and (3) are the same. The coefficient a_{ij} is defined as a dollars' worth of input from sector i required to produce a dollar worth of output in sector j in base year (1974-75) prices. This is computed directly from the nominal input-output accounts table. It may be noted that the coefficients computed from equation (3) for different years e.g. 1980-81 (in this study) in which the relative prices are different, cannot be compared because units of real outputs are different (Dervis et al. 1982, p. 22).

In consideration of the above, the national input-output table of 1980-81 was deflated to 1974-75 prices to make the table comparable to the base year table. It was not possible to get the deflator values for the sectors being considered in this study except for coal, mining and mineral fuel lubricants, that could correspond to 1974-75 constant prices. Implicit price deflators, measured as the ratio of gross domestic product at current prices to the gross domestic product at constant prices (Australian Bureau of Statistics 1984, p. 82), were available at 1974-75 prices but only up to the period 1979-80.

In the circumstances, the deflator values for different aggregated sectors were calculated by reindexing: (a) the price index of articles produced and used in the manufacturing industries; (b) the export price indexes for coal, mining and mineral lubricants; (c) the consumer price indexes for recreation, community service, transportation, and (d) the wholesale price index for electricity, gas and fuel.

Implicit price deflators had to be used for public administration and defence, wholesale and retail trade, and finance and banking sectors. For the agricultural sectors, the index of prices received by farmers was used. The salaries and wages for each of the aggregated sectors have also been deflated by a set of deflator values obtained as follows. These deflator values were calculated by reindexing the weekly wage index (obtained from the Australian Bureau of Statistics 1975b, 1980) based on 1954 constant prices. In order to do that, wage indices of adult males and females were summed and then the average indices for 1974-75 and 1980-81 were calculated. Then, the values were reindexed to get the necessary deflators for each of the sectors. The deflator values used in this study are shown in Appendix 13.

It was assumed that reindexing price indices would at least indicate a proxy of using actual deflators instead of using implicit price deflators when no other deflator values were available. Finally, it needs to be kept in mind that the procedure of deflation cannot encompass some potentially important induced effects of changes in price level of relevant variables (Jensen and West 1986a, p. 112).

Chapter 4

INTERPRETATION OF RESULTS

The analytical procedures described in chapter 2.4.3 and the energy input-output tables, constructed in the last chapter, are used to estimate the changes in energy use in Australia during the period 1974 to 1980. In this chapter, the results obtained from these analyses are discussed. First, the genesis of the present study is recapitulated followed by the interpretation of technology induced and demand induced changes in energy use together with the discussion of results. Afterwards, the explanation on the underlying process of technological changes in energy use is discussed. Then, the energy intensity of different sectors in Australia are recalculated to make a comparison to those of the Department of Resources and Energy. Lastly, the main limitation of the study is mentioned.

4.1 Introduction

It was mentioned earlier in Chapter 1 that the oil price shock of 1973-74 and its aftermath in 1979-80 induced changes in energy consumption in the Australian economy. These changes took place both in the mix of energy usage in particular sectors and in the absolute level of energy use. The Department of Resources and Energy (1987) mentioned that despite the development of some energy intensive industries, the energy intensity of most sectors has declined in recent years. However, that report considered only the direct energy use in measuring energy intensity of a particular sector. Any particular sector, in addition to directly consuming energy, consumes energy indirectly through consumption of 'energy-embodied' non-energy inputs in the production process. This induced or indirect consumption has an important bearing on total energy consumption and the energy intensity of a sector. To substantiate this notion, the present study has been conducted with a view to looking at:

(1) the changes in energy use by different sectors in Australia for the period immediately after the oil price shock of 1973-74 and further after the second oil price shock of 1979-80; and

(2) the sources or origins of these changes.

Whatever the reasons, the changes in energy use may be detected from changes in production technology and changes in final demand both in demand mix and level (Gowdy and Miller 1987b; Bruce Hannon 1982). To observe the changes in energy use and the sources thereof in Australia, the main focus of the present study was to investigate the sectoral changes in energy use arising from: (1) technological change; and (2) demand change (as described in Chapter 2).

Technology induced changes in energy use consist of both direct and indirect change. The indirect change in energy use further consists of: (i) changes in the level of energy consumptions; (ii) changes in mix of energy used; and (iii) changes in non-energy input mix used in the production process of any industry.

Demand change includes changes in demand mix and in the absolute level of demand. Changes in demand mix arise from changes in the composition of final products comprising a particular final demand.

4.2 Technology Induced Change in Energy Use

The analytical procedures used in estimating the changes in energy use resulting from different forms of technological changes were discussed earlier in Chapter 2.4.3. These procedures have been used to estimate the percentage changes in energy use required per unit of output due to changes in technology during the periods 1974 to 1980.

In Table 4.1, the estimated percentage changes in energy use required per unit of output as a result of technological change are presented. For simplicity, twenty nine sectors were aggregated into twelve sectors. The percentage changes in energy use and the actual energy requirement measured in 10^{13} joules per unit of output for these 29 sectors are shown in Appendices 14 and 15. It has been observed from the table that the percentage changes in total energy usage per unit of output due to technological changes were positive in all sectors of the economy except in the refined petroleum products sector. The effect of total technological change on energy use was largest in agriculture, manufacturing, gas utilities and service sectors. Similar results were obtained by Gowdy and Miller (1987b, p.1391) for the period 1967-72 in the United States except in service and energy (total) sectors.

Percentage changes in energy usage required per unit of output arising from different forms of technological changes - direct change, indirect change in the level in energy mix and in non-energy input mix, have also been shown in Table 4.1. It has been observed from the table that out of 12 sectors, seven sectors noticed a decrease in direct energy used during the period 1974 to 1980. However, only one energy sector, the refined petroleum products sector showed a decrease in direct energy use out of five energy sectors. Thus, the decrease in direct energy use was more pronounced in non-energy sectors compared to energy sectors. It should be mentioned that the changes in direct energy use required per unit of output have been estimated using the procedures in Chapter 2.4.3 (Equations 1-5).

Table 4.1

Percentage Change in Energy Use Required per Dollar of Output in Australia During 1974 to 1980 as a Result of Technological Change

Sector Industry	Changes in energy use					
	Direct change	Indirect change				TOTAL
		Level	Energy mix	Non-energy mix	Total	
Agriculture,forestry fishing & hunting.	2.8	20.6	1.3	2	23.9	26.7
Other mining	-15.7	3	3.6	9.8	16.4	0.7
Manufacturing excluding metal,petro.prod.	-3.2	17.8	0.1	20.2	38.1	34.9
Metal & min. prod.	-6.5	2.5	1.7	12.4	14.3	7.8
Crude oil & gas(a)	0.1	0.3	-0.2	0.7	0.8	0.9
Coal(a)	0.2	0.7	-0.1	-0.5	0.1	0.3
Ref.pet.prod.(a)	-0.4	-1.4	0.8	0.1	-0.5	-0.9
Electricity(a)	1.4	18.1	-3.4	-14.5	0.2	1.6
Gas(a)	8.6	-9.5	1.6	12.4	4.5	13.1
Construction	-4.9	23.4	8.1	26.7	58.2	53.3
Transport & Communication	-4.6	2.2	1.2	4.9	8.3	3.7
Services	-4.6	30.3	3.5	-1	32.8	28.2
Non-energy (total)	-3.6	4.3	2.9	10.3	17.4	13.8
Energy (total)	2.6	2.7	-0.6	-0.9	1.2	3.8

(a) Energy use in these sectors is measured in units of 10^{13}joules of input per 10^{13} joules of output.

With regard to indirect changes in the level of energy use, Table 4.1 indicates that only two sectors, refined petroleum products and gas utility sectors have shown decreases in energy use. The indirect change in the level of energy use was higher in the service, construction, manufacturing and agriculture sectors while in other sectors, the changes are lower. It was rather low for the oil and gas sector. The indirect change in the level of energy consumption per unit of output has been calculated using the procedures in chapter 2.4.3 (Equations 6-9).

To estimate the changes in energy use due to changes in energy input mix, the procedures mentioned in chapter 2.4.3 (Equations 10-12) have been used. It has been found that three energy sectors oil and gas, coal and electricity out of a total of twelve sectors have shown a decrease in energy use due to changes in energy mix.The finding indicates that these three energy sectors were able to reduce energy consumption required per unit of output in 1980 through substitution among energy inputs. The percentage changes in energy use required per unit of output due to change in energy input mix were not as pronounced for individual sectors as those of the indirect change in the level of energy consumption.

The analytical procedures mentioned in chapter 2.4.3 (Equations 13-15) has been used to calculate the changes in energy use per unit of output due to changes in non-energy input mix. Energy use decreased in three sectors namely coal, electricity and service sectors. This implies that these sectors were able to reduce energy use by substituting less energy intensive non-energy inputs in view of the oil price increase. However, for others, the changes in energy use were positive. It may be mentioned here that while a 26.7 per cent increase in energy use took place in the construction sector due to changes in the non-energy input mix, this sector on the other hand showed a 4.9 per cent decrease in energy use due to direct changes in technology.

Thus Table 4.1 indicates that the direct change in energy use was negative for most of the sectors while the indirect change in energy use due to changes in level and non-energy input mix were positive for most of the sectors except the coal , transport and communication, and electricity sectors. The table further indicates that, in all cases, the positive changes in indirect energy use offset the direct negative change. This was true for most of the sectors except the agriculture and energy sectors. The reasons for the above behaviour might be the fact that a particular sector was more flexible and sensitive to changes in energy price of a type when the sector consumes energy directly, than consuming energy-embodied non-energy inputs indirectly. The amount of indirect energy is inherent and fixed in the technology of production. A sector has very little or even no choice at all to change consumption of such embodied energy. The amount of indirect energy used arising from changes in non-energy input mix depends on the energy intensiveness of direct non-energy inputs and changes in efficiency in energy production. The underlying process of non-energy input substitution and hence the changes in energy use will be discussed later on.

4.3 Demand Induced Change in Energy Use

In stating the objectives that the changes in energy use may originate from changes in final demand, it was assumed that, there were increases or decreases in prices of energy types, in other words, relative prices between energy resources or between energy and non-energy resources changed the consumer's buying pattern had to change accordingly until the utilities so derived were maximized (assuming further that the consumers were utility maximizing). In the context of this study, these changes in buying patterns were reflected in changes in the share of industrial products constituting a particular final demand e.g. export or household. These changes may be regarded as changes in demand mix. Changes in the proportion of industrial products have varying impacts on the level and mix of energy use. Further, with the growth of the economy, the level of demand of individual industrial products may undergo changes. These changes in the level of industrial products and therefore, the changes in the level of final demand make changes in the requirement of energy.

The procedures used in calculating the changes in energy use resulting from changes in final demand have been discussed in Chapter 2.4.3. The percentage changes in energy use required per unit of output due to changes in final demand were calculated. The results are presented in Table 4.2. The detailed analysis, that is, the percentage changes in energy use

Table 4.2

Percentage Change in Energy Use Required per Dollar or Joule of Output in Australia as a Result of Demand Change and Technological Changes During 1974 to 1980.

	Demand Change			Technological Change	Total
	Demand Mix	Level of Demand	Total		
Agriculture, etc.	-15.0	27.0	12.0	26.7	38.7
Other mining	-10.5	15.3	4.8	0.7	5.5
Manufacturing, excluding metal, petrol, min. prods.	-0.7	14.6	13.9	34.9	48.8
Metal and Metal prods.	-5.9	15.9	10.0	7.8	17.8
Oil and gas	-12.0	35.0	23.0	0.9	23.9
Coal	-5.0	20.5	15.5	0.3	15.8
Refined petroleum prods.	-13.0	17.5	4.5	-0.9	13.6
Electricity	-4.5	18.1	13.6	1.6	15.2
Gas	-3.5	19.3	15.8	13.1	28.9
Construction	2.0	14.1	16.1	53.3	69.4
Transport and comm.	-9.7	26.6	16.9	3.7	20.6
Services	0.2	13.7	13.9	28.2	42.1
All Sectors	-12.3	37.8	25.5	15.8	41.3

and the changes in the actual requirement of energy measured in 10^{13} joules per unit of output for 29 sectors are provided in Appendices 16 and 17.

The percentage changes in energy use due to change in demand mix have been calculated using equations 17-19 mentioned in chanter 2.4.3. It is apparent from Table 4.2 that energy use per unit of output due to changes in demand mix decreased for all sectors in the economy except the construction and service sectors. Similar results were obtained by Gowdy and Miller (1987b, p. 1392) for the period 1972-77 except the agriculture and mining, and service sectors which showed positive results.

The effects of changes in the level of final demand on percentage changes in energy use have been calculated for all sectors by using equations 20-22 mentioned in chapter 2.4.3. The percentage changes in energy use were however positive. The findings were the same for the United States for the period 1963-67, 1967-72 and 1972-77 (Gowdy and Miller 1987b, p. 1392). In Australia, the total effect of a demand change was positive for all sectors in the economy.

Table 4.2 further manifests that the effect of demand change on total changes in energy use per dollar of output was higher in most sectors in the economy than those resulting from technological changes. The important reasons could be the fact that the changes in production technology involve a relatively longer time span than the changes in final demand. Further, the period 1974 to 1980 considered in this study was not long enough to make any substantial change in the technology of production.

4.4 Explanation on the Process of Technological Change

It was observed from Table 4.1 that the impact of indirect change on energy use was more than the direct change. As mentioned earlier, two major determinants of changes in indirect energy consumption level may be identified. First, a change in energy intensiveness of direct inputs, and second, a changing efficiency in energy output . As an example of the first, the construction sector increased indirect energy consumption per unit of output by 58.2 per cent in 1980 compared to 1974 (Table 4.1). This increase was largely due to an increased amount of energy embodied in direct non-energy inputs such as inputs from the manufacturing, metal products, and transport and communication sectors (Table 4.5, shown later).

Energy consumption levels are also affected by changes in the efficiency of energy production. An increase in energy efficiency of energy inputs can be defined as a decrease in the number of petajoules of input required to produce a petajoule (10^{15} joules) of energy output and vice versa for a decrease in efficiency. Estimates of numbers of 10^{13} joules required for each type of energy are presented in Table 4.3.

Table 4.3

The Number of 10^{13} joules Required per 10^{13} joules of Output in Energy Sectors in Australia in 1974 and 1980

Energy type	Year 1974	1980	Percentage change
Crude oil & gas	1.014	1.0238	0.9
Coal	1.0096	1.0124	0.3
Ref.pet.prod.	1.1326	1.1231	-0.8
Electricity	1.9336	1.9662	1.7
Gas	1.724	1.9494	13.1
TOTAL			3.8

It is evident from Table 4.3 that the energy efficiency decreased in all energy sectors except the refined petroleum products sector. This was due to conservation measures taken in view of high prices for crude oil, because crude oil was the single most important energy input in the refined petroleum products sector (Department of Resources and Energy 1987, p. 105). The decrease in energy efficiency in the electricity sector was caused mostly by the fact that the requirements of coal which constitutes approximately 80 percent of total energy input, to produce a unit of electricity, has increased by 39 percent during the period 1974 to 1980 (Department of Resources and Energy 1987, p. 113). In a similar way, the decrease in energy efficiency in the gas sector can be analyzed. Petroleum products nec (not elsewhere classified) is the most important energy input for gas. Its share as an input to total energy input required for gas increased from 45 percent in 1974 to 74 percent in 1980. The percentage increase in the requirement of the petroleum products nec per unit production of gas was 47 per cent during the period 1974 to 1980 (Department of Resources and Energy 1987, p. 114). In Australia, there was a decrease in energy output efficiency during the period 1974 to 1980 due to a large increase in energy requirement in the electricity and gas utility sector.

Indirect levels of energy consumption varied inversely with energy efficiency. During the period 1974 to 1980, the overall efficiency in energy production decreased by 3.8 percent (Table 4.3) while the indirect level of energy use increased by 3.8 percent (Table 4.1).

Energy mix was also an important determinant of energy use. It is observed from Table 4.3 that in 1974 if 1 x 10^{13} joules of coal were substituted for electricity or gas utility a net increase of (1.9336-1.0096) x 10^{13} joules that is, 0.924 x 10^{13} or (1.724 - 1.0096) x 10^{13} joules that is, 0.7144 x 10^{13} joules of energy consumed would result, respectively.

In Table 4.4, the change in the proportion of total energy use of individual fuel type changed from 1974 to 1980 has been indicated. During this period energy use increased by 2.7 percent in the economy due to changes in the level of energy consumption (Table 4.1). In this period, despite a decrease in the use of crude oil and gas, refined petroleum products, and electricity, however, the net effect was an increase in energy use. The possible reasons could be the fact that the share of coal (though least energy intensive) has increased its share from 37.9 per cent in 1974 to 48.9 per cent in 1980.

Table 4.4

Total Energy Consumption in Australia (In 10^{13} joules) in 1974 and 1980.

Energy type	Year			
	1974		1980	
	Amount	Percentage	Amount	Percentage
Crude oil & gas	149640	26.8	179260	22.7
Coal	211960	37.9	385550	48.9
Ref.pet.prod.	135350	24.2	139320	17.7
Electricity	59370	10.7	83040	10.5
Gas	2000	0.4	1640	0.2
TOTAL	558320	100	788810	100

*Percentage increase in total energy consumption during the period was $\frac{78810 - 558320}{558320} \times 100$

= 41.3.

From Table 4.1 the negative relationship between the changes in energy use due to substitution among non-energy inputs and the changes in direct energy use was identified. This was because the non-energy inputs were substitutes for one another to a certain extent. So, the direct energy was replaced by packaged energy embodied in the non-energy inputs.

Changes in the mix of non-energy inputs made a large change in energy use (Table 4.1). As mentioned earlier, Table 4.1 does not provide any information of the underlying process of input substitution. To have a clearer picture of how the substitution among the non-energy inputs and hence its impacts on total energy use took place, further manipulation of matrices was carried out with the construction sector as an example. This is explained below.

It was found in Table 4.1 that the changes in energy use in the construction sector due to changes in non-energy input mix was the highest (26.7 percent). The process of these changes are explained in Tables 4.5 and 4.6. The construction of matrices and estimation of coefficients in these tables can be explained as follows. Column 1 in Table 4.5 shows the direct coefficients for the construction sector for 1974. These coefficients were calculated from a matrix where the flows from energy sectors were replaced by 1980 values (referred to as A7480). Column 2 indicates the direct coefficients for 1980 (referred to as A80). Columns 3 and 4 give the direct-indirect energy coefficients from A7480 and A80 matrices for each sector, respectively. Finally, the columns 5 (using A7480) and 6 (using A80) give the direct-indirect energy coefficients or requirements from each sector to produce one dollar's worth of output in the construction sector. These coefficient values in columns 5 and 6 have been calculated as follows. First, direct non-energy coefficients of all sectors were pre-multiplied by a diagonal matrix with the direct and indirect energy coefficients of each sector on the main diagonal and zero elsewhere. This exercise gave a matrix of proportionate energy input coefficients. Two such matrices were calculated for A7480 and A80. A comparison of these two matrices indicates which non-energy sectors caused the greatest change in proportionate energy use in the economy. This is provided in Table 4.7 (to be discussed later). Secondly, the column representing energy requirements for non-energy input used by the construction sector was isolated from the proportionate energy input coefficients for A7480 and A80 matrices. This was done for two periods 1974 and 1980.

It is observed from Table 4.5 that the amount of direct non-energy inputs used per unit of production in the construction sector also increased. This table also indicates that the direct and indirect energy requirements per unit of output in these non-energy sectors also increased simultaneously except in other mining, service and refined petroleum products sectors. Alternatively, these increases in energy requirement had increased the energy intensiveness of direct non-energy inputs.

It is evident from Table 4.6 that the percentage of total direct and indirect energy requirements from the construction sector per unit of its own production decreased from 23.4 per cent in 1974 to 6.8 per cent in 1980. The percentage share of energy requirements from the manufacturing, metal and metal products, transport and communication, and service sectors increased. All these changes in energy requirements must have been due to changes in the mix of non-energy inputs used in these sectors.

A similar process of non-energy input substitution and hence its impact on total changes in energy use was also investigated for all sectors in the economy (Table 4.7). The above table

Table 4.5

Proportionate Energy Coefficients for the Construction Sector measured in 10^{13} joules in Australia for the periods 1974 and 1980

Sectors	Direct	Coefficients	Direct & Indirect energy coefficients (a)		Direct & Indirect energy coefficients (b)	
	A7480	A80	A7480	A80	A7480	A80
	1	2	3	4	5	6
Agriculture	0.0005	0.0006	1.4018	1.7502	0.0005	0.0012
O.min.	0.0038	0.0053	3.8567	3.1621	0.0041	0.0109
Manufacturing	0.0306	0.0677	2.5972	3.7194	0.0329	0.1389
Metal & Min. Products	0.0786	0.1594	4.5243	5.0258	0.0846	0.3272
Construction	0.048	0.025	1.0766	2.0524	0.0517	0.0513
Transport & Comm	0.023	0.0446	9.1435	9.8673	0.0248	0.0915
Service	0.021	0.0628	1.0845	1.0578	0.0226	0.1289
Oil & gas	0.0354	0.0354	1.014	1.0223		
Coal	0.002	0.002	1.0093	1.0115		
Ref.pet.prod.	0.1702	0.1702	1.1309	1.1213		
Electricity	0.0982	0.0982	1.0332	1.9669		
Gas	0.0072	0.0072	1.7388	1.9852		

(a) indicates the direct and indirect energy coefficient from the A7480 and A80 matrices for each sector.

(b) indicates the direct and indirect energy requirements from each sector to produce one dollar's worth of output in the construction sector.

Table 4.6

Change in energy use per dollar of production in construction sector as a result of substitution among non-energy inputs (measured in 10^{13} Joules).

	Proportionate 10^{13} Joules (A7480)		Proportionate 10^{13} Joules (A80)		Change in Coefficient
	Coefficient	%	Coefficient	%	
	1	2	3	4	5
Agriculture	0.0005	0.2	0.0012	0.2	+ .0007
Other mining	0.0041	1.9	0.0109	1.5	+ .0068
Manufacturing	0.0329	14.9	0.1389	18.5	+ .1060
Metal Products	0.0846	38.2	0.3272	43.6	+ .2426
Construction	0.0517	23.4	0.0513	6.8	- .0004
Transport & Communication	0.0248	11.2	0.0915	12.2	+ .0667
Services	0.0226	10.2	0.1289	17.2	+ .1063
TOTAL	0.2212	100.0	0.7499	100.0	+ .5287

shows how much the percentage changes in energy use resulted from changes in the use of direct non-energy inputs required per unit of output of different sectors in the economy. The table further reflects that the percentage increase in energy use per unit of output required in 1980, compared to 1974 in the agriculture, construction and service sectors, were 88.5, 23.9, and 47.8, respectively. On the other hand, the use of indirect energy embodied in non-energy inputs decreased in the electricity, refined petroleum products and service sectors. The energy requirement measured in 10^{13} joules per unit of output arising from usage of direct non-energy inputs by each sector for the period 1974 to 1980 are provided in Appendix 18. The above results obtained from Tables 4.5, 4.6 and 4.7 imply the substitution of non-energy inputs and the resultant changes in energy consumption.

4.5 Energy Intensity in the Australian Economy

The Department of Resources and Energy (1987) indicated a particular sector or a group of sectors being either more energy efficient or less energy efficient by looking at the energy intensity per dollar of GDP. These have been discussed in Chapter 1. These energy intensity values of individual sectors to explain energy efficiency were misleading as the reported energy intensities for different industries reflected the direct energy use only.

Factor (energy) intensities are better measured and understood through industrial interdependencies. In Chapter 1, a relevant question was therefore asked to investigate whether a different pattern appeared when the indirect as well as the direct energy usages were considered. Accordingly, the energy intensity of different sectors were recalculated. These are presented in Table 4.8. The table shows increases in energy intensity for all sectors compared to those by the Department of Resources and Energy (1987).

The recalculated energy intensity values in the agriculture, food, textiles, wood and paper sectors were more than double the reported figure. This implies that these industries had stronger linkages and flow-on effects on the economy than the rest of the sectors. Alternatively, it indicates that the growth of any of these sectors would induce relatively higher consumption or demand for energy due to indirect effects. The underlying process of these indirect changes were mentioned in the previous section.

Consideration of the direct and indirect energy use per unit of Gross Domestic Product of a particular sector has advantages over the one considering the direct energy use only. That is, if it is possible to forecast the growth of Gross Domestic Product of different sectors and if the technology of production remains either constant or changes as predicted, the correct estimation of energy requirement may properly be ascertained. On the other hand, any attempt to measure the sectoral energy requirement considering only the direct energy consumption,

Table 4.7

Percentage Share of Energy Requirements of Direct Non-energy Input Coefficients Measured in 10^{13} joules in Australia for the Periods 1974 and 1980

	Agr.		O.min		Misc. MFg.		Oil & gas		Coal		Ref.pet. prod.	
	1974	1980	1974	1980	1974	1980	1974	1980	1974	1980	1974	1980
Agriculture	44.9	32.7	0.005	0.1	54	19.7	0	0	0	0	0	0
O.min.	0.04	0.04	38.3	23	0.2	0.1	0	0	37.5	50	0	0
Manufacturing	2.7	31.6	3.7	7	25.3	47.7	0	10	0	0	18.7	58.3
Metal Products	5.5	3.8	21.2	23.8	4.7	11.1	0	40	37.5	30	31.2	0
Construction	26	9.9	10.6	13	0.2	8.7	0	20	12.5	10	31.4	16.7
Transport & Comm	17.5	12.6	4.8	15.7	4.6	6.1	0	20	12.5	10	18.7	16.7
Services	3.4	9.4	11.4	17.4	1	6.6	0	10	0	0	0	8.4
TOTAL	100	100	100	100	100	100	100	100	100	100	100	100
Aggregate change in energy use in Australia	88.5		1.5		4.2		100		0		-25	

Met.& Min. prod.		Elect.		Gas		Const.		Trans. & Comm		Service	
1974	1980	1974	1980	1974	1980	1974	1980	1974	1980	1974	1980
0.2	0	0	0	0	0	0.2	0.2	0.4	0.2	0.04	0.3
8.7	5.8	0	0	0	0	1.9	1.5	0.5	0.1	0.02	0.1
5.6	10.3	4.2	0	3.2	4.6	14.9	18.5	7.9	10.5	71.4	23.7
69.4	65.3	21.4	16.7	12.3	7.1	38.2	43.6	36.8	38.1	1.2	11.6
9.6	7.6	42.9	12.5	39.4	5.5	23.4	6.8	39.7	19.4	3.7	11.7
6.3	6.5	28.6	37.5	43.2	74.1	11.2	12.2	10.4	18.1	62	15.9
0.2	4.5	7.1	29.1	1.9	8.7	10.2	17.2	4.3	13.6	17.4	36.7
100	100	100	100	100	100	100	100	100	100	100	100
49.3		71.4		57.8		239		-73.7		73.4	

Table 4.8

Energy Intensity in Australia by Sector (Petajoules per 1979-80 billion GDP)

	1974-75		1980-81	
	As per Report 1987[a]	Study result	As per Report 1987	As per Study
Agriculture	5.79	11.0	6.95	13.9
Other mining	NA	NA	NA	NA
Oil & gas	NA	.0149/PJ	NA	0.177
Coal	NA	.0046/PJ	NA	0.0017
Mining (Total)	9.43	11.5	9.81	10.05
Food, beverages, tobacco	25.7	57.2	25.36	60.8
Textiles	7.73	19.0	7.16	24.3
Wood etc	11.88	21.6	11.46	22.3
Paper	23.56	57.0	20.80	60.10
Chemical	NA	*	NA	*
Petroleum products	NA	.0281/PJ	NA	.2203/PJ
Chemical and petroleum products	152.68	165.3	130.08	190.4
Non-metallic minerals	99.48	110.0	86.11	106.5
Basic metal	180.44	250.0	148.36	255.8
Fabricated metal products	4.50	6.5	4.86	8.9
Transport equipment	4.51	8.7	4.68	1.2
Miscellaneous manufacturing	4.23	6.6	3.89	8.1
Manufacturing (Total)	44.63	62.9	40.74	80.8
Electricity	NA	1.3301/PJ	NA	.7445/PJ
Gas utilities	NA	1.4279/PJ	NA	1.8768/PJ
Water, sewerage & drainage	NA	NA	NA	NA
Electricity, gas and water (Total)	290.40	340.2	275.06	188.3
Construction	3.91	4.27	4.45	4.90
Commercial services	1.73	5.9	1.80	9.3
Wholesale & retail trade	NA	5.1	NA	5.9
Transport, storage and communication	NA	75.7	NA	64.9
Finance etc. & business services	NA	0.95	NA	1.32
Public administration	NA	3.4	NA	1.83
Community service	NA	5.1	NA	4.83
Recreation	NA	3.28	NA	5.0

NA: Not available . * GDP of Chemical sector could not be isolated.
a: Department of Resources and Energy (1987, p. 13-14).

may end up with an underestimated value if the particular sector's indirect energy requirement is substantial.

4.6 Limitation of the Study

In this study, the sectoral changes in energy use in Australia during the period 1974-75 and 1980-81 have been estimated. In order to do that, first, three sets of matrices, energy make matrices (of dimensions 5 x 28), energy absorption matrices (of dimensions 28 x 29), and energy flow matrices (of dimensions 5 x 29) were prepared for the above periods. These matrices were required ultimately to construct the energy input-output tables (of dimensions 29 x 29) for Australia for these two periods. The construction of all these matrices involved a considerable amount of time prior to starting the subsequent analyses and manipulation of data required in this study by using the procedures outlined in chapter 2.4.3. Further, to aggregate the basic input-output tables (of dimensions 109 x 109) into 29 x 29 commodity by industry took a long period of time.

Due to limitations of time as explained above, this study had considered the total usage of energy and the changes in energy use without any consideration of fuel type for different industries. If the effect of changes in technology and final demand on total energy use had been estimated by fuel type for individual sectors, the sector(s) influencing energy use of a particular type(s) due to either changes in energy mix or non-energy input mix, or demand mix or level in demand could have been properly identified. The findings, then could suggest policy directions for a particular fuel type(s) for a sector. It may be mentioned that the present study, instead of looking at the impact of prices on energy use, investigates only the nature of changes in energy use. Also, the study does not contain the information on: (i) to what extent the energy resources are being substituted for one another, and (ii) the extent to which the non-energy resources are being substituted for each other. For these analyses, econometric studies would be necessary. The attempt of the study was, therefore, only to investigate to what extent the total changes in energy use resulting from the above substitutions (among or between the energy and non-energy resources) was due to technology influences and demand influences.

Chapter 5

SUMMARY, CONCLUSION, POLICY IMPLICATIONS AND FUTURE RESEARCH

5.1 Summary

The oil price shock of 1973-74 forced producers and consumers to change directions several times in their search for optimal combinations of energy and non-energy inputs. In Australia, the effect of the oil price shock brought about changes in total energy consumption (in energy mixes and levels).

The underlying mechanism of the search for optimum input combinations can be explained in the way that the oil price increase made changes in the relative prices of both energy and non-energy resources, and also changes in the relative prices of different types of energy. These changes in relative prices led to changes in the technology of production used and in consumers' buying pattern. The changes in the technology of production have bearings on the amount of energy and non-energy input used over time by a firm (industry). On the other hand, the changes in the buying pattern are reflected in changes in the share of commodity baskets. These changes in the commodity baskets influence the amount of energy and non-energy goods and services purchased. Thus, the changes in the technology of production and commodity baskets influence the amount of energy and non-energy resources used or purchased.

The Department of Resources and Energy (1987) indicated a particular sector or a group of sectors being either more energy efficient or less energy efficient by looking at the energy intensity value for each sector. This notion of either increase or decrease in energy efficiency, however, is misleading as the reported energy intensity values for different industries reflect the direct energy use only. A relevant question was whether or not a different pattern of energy efficiency among the sectors appeared when the indirect (i.e. energy embodied in non-energy inputs required in production) as well as the direct level of energy usage are considered. This direct and indirect energy use can be captured in the technology of production with the help of input-output analysis especially by using the Leontief inverse.

Thus the main focus of the study was to investigate to what extent the total changes in energy use during the period 1974 to 1980 were technology induced and demand induced and with this end, the input-output analysis as a technique was used. The national input-output tables for 1974 and 1980 were used to reflect the situation, immediately after and the post oil price shock. The energy use data were obtained from the Department of Resources and Energy (1987).

In order to estimate the total changes in energy use, two energy input-output tables each having dimensions of 29 x 29 commodity by industry were constructed for the periods 1974-75 and 1980-81. To construct these energy input-output tables, first, energy make matrix, energy absorption matrix (a dimension of 28 x 29 commodity by industry) and energy flow matrix (a dimension of 5 x 29 commodity by industry) were prepared for the above period. The construction of these matrices and the procedures thereof, were mentioned in Chapter 3.

As constructed, the energy input-output tables of 1974 and 1980 were used to estimate the total changes in energy use arising from changes in technology of production and final demand. The interpretation of the results and their policy implications are mentioned in Chapter 4.

Technology induced changes in energy use was decomposed into direct change and indirect change. Indirect change in energy use was further decomposed into (i) indirect change in the level of energy consumption; (ii) changes in energy mix; and (iii) changes in non-energy input mix. Demand induced changes in energy use included: (a) changes in the mix of final demand; and (b) changes in the level of final demand.

It was observed that the indirect changes in energy use were more pronounced than those of the direct changes. It offsets the direct negative changes in energy use. And the resultant effects of technology induced changes in energy use were positive. The underlying process of the indirect changes in energy use was further studied for all sectors of the economy.

Two major determinants of changes in indirect energy consumption were identified. These determinants were: (i) changes in energy intensiveness of direct inputs, and (ii) a changing efficiency in energy output. Using the construction sector as an example, the detailed underlying process of non-energy input substitution and their impact on indirect energy consumption was investigated.

The effect of changes in final demand for goods and services on total energy use especially the effect of changes in demand mix was negative in most of the sectors, while the changes in the level of final demand had positive effects on energy use. The final outcome of demand induced changes on energy use was, however, positive. Further, demand induced changes on energy use were greater than those of technology induced changes. The possible reasons for this could be the fact that the technology of production was less flexible to change during 1974 to 1980 compared to final demand.

Energy intensity of a sector defined as the consumption of energy (both direct plus indirect) per billion dollars of Gross Domestic Product (at 1979 prices) was calculated for 29 sectors for the period 1974 and 1980. These energy intensity values were higher compared to those calculated (considering only the direct consumption of energy) by the Department of Resources and Energy (1987). Thus, a different pattern of energy intensities for different industries appeared.

5.2 Conclusion

It may be mentioned from this study that the analysis of energy use in industries should not depend on direct energy consumption as the sole basis of measuring energy efficiency. If one has to assess accurately which sectors of the economy are becoming more or less energy efficient, one must take into account each sectors' indirect energy use. If energy mix and the impact on energy use of substitution among non-energy inputs is ignored, those sectors that are making great strides in becoming more energy efficient may not be recognized as such, because these savings are not in direct energy use. Sectors that are decreasing their use of direct energy may, as the evidence in Table 4.1 suggests, be doing so by purchasing more energy intensive non-energy inputs.

5.3 Policy Implications

This study has offered an indication of how the total changes in energy use can be influenced by the direct and indirect effects. The indirect effects, of level, energy mix, and non-energy input mix have further been analyzed to explain the underlying process of energy use. The total energy saving technological changes due to changes in energy mix and non-energy input mix occurring in the coal, crude oil and gas, and electricity sectors can be defined as energy efficient improvements. While the demand mix or market basket effect that saved the total energy use whether induced by the price or behaviour can be defined as energy conservation actions (Hannon 1982, p. 272).

All the results discussed in Chapter 4, demonstrate that the energy policies (pricing, taxing, quota or rationing, conservation, etc.) based on the direct energy use, either to encourage or discourage consumption of energy will not be sufficient. It may so happen that the indirect effect may outweigh any decrease in energy use arising from the direct energy consumption as was the evidence for all sectors in Australia (Table 4.1). So, one must know and understand the relative importance of the indirect energy use in different sectors. Besides, the knowledge of the impact of demand mix and the level of demand is important. It is beyond the control of energy producing sectors to comprehend correctly the nature and extent of changes in final demand in different non-energy sectors and its impact on the total energy consumption. In this case, the findings of the present study have provided an indication of the likely impacts of final demand on total energy use. More broadly, if it is possible to estimate and forecast the changes in final demand (mix and level), an account of proper energy requirement can be made (Hannon 1982, p. 251).

5.4 Future Research

Due to the limitation of time, as mentioned in Section 4.6, this study considered only the total changes in energy use irrespective of fuel types. Further, due to lack of energy data at commodities it was not possible to investigate the changes in energy use at commodity level.

So, future research studies may be carried out on changes in energy use by fuel type at commodity level. This will require data on energy use at commodity detail and to this end, necessary modifications and enlargement of the present input-output tables will be necessary by including more fuel types as commodities. A detailed energy study, would then be able to show changes in energy use for specific fuel type(s) by a sector. Further, if it is possible to estimate the future changes in final demand (through-econometric studies), simulation of energy requirements from individual fuel type(s) and sources (renewable and non-renewable energy sources, for example) can be ascertained. In this way, the growth of energy requirements of different fuel type(s) from different sources may be estimated. Besides, energy use by fuel type would indicate which particular fuel type has been used in fixed proportion or inelastic in use over the years by a sector or a group of sectors. These results may then suggest policies to make options for fuel type being used in variable proportion over others used in fixed proportion over time. Simultaneously, if the growth of the domestic energy supply and the usage of a fuel type(s) are possible to estimate, the comparison between the two estimates may convey the likely gap of the energy situation. Subsequently, whether this gap is substantial enough to hinder the growth of a sector can be forecast. With further analyses of the energy use data by sectors, the energy cost of goods and services produced by a sector(s) in the economy can be estimated. This type of works were carried out in the United States by Bullard III (1974), Bullard et al (1978), Herendeen et al (1981), Bruce Hannon (1982), and Hannon and Blazeck (1984).

In this study, average energy intensity per unit of Gross Domestic Product was calculated. Marginal energy intensity* by fuel type and by sector may be estimated. This exercise will have advantages over the estimation of average energy intensity when one is trying to calculate the energy savings potential of a shift in production and consumption of goods and services (Hannon and Blazeck 1984, p. 88).

Further, the indirect energy use associated with capital formation can be analyzed by incorporating a capital inputs matrix. This inclusion would show inputs needed to create

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* Marginal energy intensity represents the total energy the direct and indirect energy required for the most recent unit change in output (Hannon and Blazeck 1984, p. 86).

sufficient new capital to permit a one-unit increase in total output by each sector. Models based on capital coefficient matrices have the advantages of being able to identify the energy content of investment programmes as well as that of current production (James 1980b, p. 176).