AN ENERGY ANALYSIS FOR A PINUS RADIATA PLANTATION

by

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STATEMENT OF ORIGINALITY

Except for the advice and assistance acknowledged this thesis is my own original work.

signed K.F. Wells

K.F. Wells

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ABSTRACT

An Energy Analysis of a Pinus Radiata Plantation

An analysis of energy usage in a radiata pine plantation near Tumut, N.S.W., reveals that harvesting was easily the most energy-intensive operation of nine examined, accounting for four-fifths of the energy used. New roading was next, followed by site preparation, road maintenance, pruning then protection. Relatively little energy was expended in nursery work, plantation establishment and plantation tending. Energy inputs were grouped according to five categories, namely fuel, repairs, steel, goods and services, and human labour. The requirement for liquid fuel accounted for nearly three-quarters of the total energy inputs.

Using a simple model of plantation operations, energy requirements over a forty year first rotation were estimated to total 5.4 GJ/ha.yr assuming semi-mechanized harvesting of normally merchantable logs and a 25 km haul to the processing plant. The primary sources supplying this energy in 1977/78 are estimated to have been oil 86%, coal 13% and other 1%.

Tumut plantations could yield enthalpy equivalent to 173 GJ/ha.yr assuming direct combustion of wood delivered to the door of the processing plant. If normally non-merchantable boles plus stumps were counted as potential energy output, then an additional 47 GJ/ha.yr would be available. The theoretical maximum net energy yield from the plantation is 168 GJ/ha.yr for merchantable boles only, or 215 GJ/ha.yr if wood usually left in the forest is included. Corresponding energy ratios are 32:1 and 27:1.

- Abstract -

A large loss of energy is entailed in burning wood of eucalyptus forest cleared during preparations for planting: if enthalpy of combustion of this wood is included as an energy input to establishing a plantation, then the theoretical net energy yield from the plantation drops to between 85-123 GJ/ha.yr, and the energy ratio to around 2:1. This changes the energy sequestered in logs from 270 MJ/m^3 to 4880 MJ/m^3.

The Tumut data form the bases for forecasting that the annual requirement for energy for the whole Australian plantation estate will rise from 3.6 PJ in 1985 to double this figure shortly after the turn of the century. By the year 2020, when the plantation estate might be 1.4 million hectares, the annual requirement for energy is expected to be fairly constant at about 8.7 PJ. These estimates assume an annual planting rate of 30,000 ha and allow for the different energy requirements of second rotation plantations, and for more mechanized harvesting, with an average haulage distance of 50 km.

The net energy yield for the whole plantation estate is forecast to be 58.2 PJ in 1985, rising to 147.3 PJ in 2020. A maximum of 14.4 PJ of liquid fuel in the form of methanol could be produced from the non-merchantable boles and stumps from plantations, theoretically making plantation forestry self-sufficient in energy.

Plantation forestry is a particularly energy-efficient form of land use but one which presently relies heavily on liquid petroleum fuels.

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Chapter One

ENERGY ANALYSIS: THE CONCEPT AND OBJECTIVES

Purpose

Modern society is heavily dependent on fossil fuels, particularly derivatives of petroleum. Sharp increases in prices and, perhaps more importantly, the realization that the end of world stocks of oil is in sight has led governments, companies, and individuals to take stock of their use of energy. Government and industry need to know at what rates the various commercial sources of energy are being depleted by different processes. This allows them to anticipate the additional drain on resources which will be brought about by expansion of a particular industry, the consequences to industry (and society) of shortages of particular forms of energy and the potential, or the need, for substituting one form of energy for another. This knowledge also provides a basis for using energy rationally and perhaps introducing economies through more energy-efficient working.

In its simplest form 'taking stock' involves keeping account of energy used directly (*direct* energy) in operations over a certain time span or per unit of output. A full energy analysis is concerned with the direct and indirect energy used in a process. As an example of *indirect* energy, in a manufacturing process which uses metal parts, a certain amount of energy is embodied or sequestered in the parts themselves. This consists of the energy which went into the process of shaping, packaging and transporting those parts and a share of the energy used in mining and processing the ore to produce the particular metal. A more universal example of indirect energy is that energy which is required to provide energy in utilizable form at the point of use. In industrialized societies it is the energy sector itself which consumes more energy than any other sector. Chapman *et al.* (1974) draw attention to the fact that more than 30% of the total energy consumed in Britain is used to provide that country with its energy, i.e. almost one-third of total energy consumption is used to convert primary energy sources to forms in which the energy is finally utilized. The figure is similar for Australia: 28% of the total primary energy supplied in 1979/80 was used in conversion processes, four-fifths of this 28% being assoicated with generation and transmission of electricity (Anon., 1981a).

Even in its simplest form analysis of energy use provides a means of identifying the steps in a process which have high energy demands. These operations can then be examined to see if energy savings might be achieved through more efficient working methods. Alternatively, the consequences, in energy terms, of changed management, or alteration to process steps, can be predicted if energy inputs to the various stages are known or can be estimated. Full energy analyses can provide reasonably precise information for energy budgeting valuable to both Management and authorities responsible for maintaining energy supplies. If internationally recognized methodology is adopted comparison of energy inputs and outputs for different production pathways is made easier.

- Chapter 1 -

How is Energy Defined?

In energy analysis, or energy accounting, the unit of account is the joule. A joule is the work done by a force of one newton when its point of application moves one metre in the direction of the force, or work done or heat generated by a current of one ampere flowing for one second against a resistance of one ohm. One joule per second is equal to one watt of power. The state of entropy of a substance determines its capacity to do work - the lower the entropy the greater the capacity of a substance's thermal energy to do work (see Lustig, 1979; Rotty and Van Artsdalen, 1978). Finney (1976) notes (page 3) that

> in a universe governed by the second law of thermodynamics under which all systems tend spontaneously to states of higher entropy, fuels (having low entropy) are unlikely states of matter and their value is enhanced as a consequence of their scarcity.

Ideally, available work, which is closely related to Gibb's free energy (the maximum amount of work obtainable from a mechanical or chemical process) should be used as a measure of the energy of a substance but, because of the difficulty in calculating this, gross enthalpy of combustion is generally used instead (IFIAS, 1974, section 4; Slesser, 1976). Gross enthalpy is the total heat content of a system, combustion taking place in air at one bar pressure and 0°C, with the products returned to these standard conditions. Table 1.1 shows gross enthalpy of combustion of some common fuels.

Methodology of Energy Analysis

A workshop organized by the International Federation of Institutes of Advanced Studies (IFIAS, 1974) laid down some ground-rules and

Table 1.1 Gross enthalpy of combustion of common fuels (Source: Australia, Department of Primary Industry, 1978).

	GJ/tonne	MJ/litre
Motor spirit	47.14	34.68
Auto distillate	45.79	38.28
Aviation gasoline	47.35	33.53
L.P. gas (approx.)	50.36	26.25
Black coal (N.S.W.)	27.91	
Natural gas (W.A.)	38.19	
Firewood (air-dry)	16.20	
Coke	25.13	
Methanol	22.40	(from Stewart *et al.*, 1979)

GJ = gigajoules = 10^9J; MJ = megajoules = 10^6J

conventions for energy analysis. The recommendations of this workshop were confirmed at a second workshop (IFIAS, 1975), resulting in a methodology for energy analysis which is internationally recognized. Others have added to this methodology (Bullard *et al.*, 1976; Perry *et al.*, 1977) or investigated its general suitability for specific applications (Finney, 1976; Pearson, 1977), but in this study I have adhered to IFIAS conventions.

Two main techniques are employed: process analysis and input-output analysis.

Process Analysis

This is the preferred form of energy analysis. It proceeds along lines already indicated, i.e. direct and indirect energy required at each step of aprocess is summed, together with energy sequestered in materials and machines used in the process, to arrive at the *gross energy requirement*. If the products of a process, including intermediate by-products, are destined for combustion as fuel then the *net energy requirement* is the gross energy requirement less the gross enthalpy of combustion of these products.

More often than not, energy sequestered in at least some of the goods and services used in a process is not known because process analyses for these goods and services have not been carried out. We then have recourse to a technique which hinges on knowing the dollar value of these goods or services.

Input-output Analysis

The energy which is sued to manufacture or provide a dollar's worth of a commodity or service can be found for some countries, including Australia, from input-output table spublished periodically. Input-output tables show the contribution, in dollar terms, of each sector of the economy including energy sectors, to each other sector, enabling us to determine the approximate energy sequestered per dollar value of the mix of goods and/or services produced by any sector. Published papers, such as those by Wright (1974), Kashkari (1978), Herendeen (1978) and Leontief (1980), can be consulted for a full explanation of the rationale of the method but the mathematical argument involved is as follows:

> if the tables show x dollars worth of a particular energy source is required to produce one dollar worth of goods in a particular sector then, knowing the price per unit of that source of energy and the gross enthalpy of combustion, it can be calculated that y joules of energy from that source are sequestered per dollar value of those goods.

Calculations are continued until all the energy sources used in producing the goods have been taken into account.

While input-output tables provide a convenient and rapid method of estimating embodied energy once energy coefficients have been calculated, the estimates for individual products will not be as accurate as those arrived at by process analysis because numerous different products are lumped together to make up 'sectors', (see ABS, 1979), and there are often large errors, usually of omission, in gathering national statistics.

Another disadvantage of using the input-output method is the time lag between gathering statistics and publishing input-output tables and energy per dollar coefficients. The final version of the Australian national accounts for 1968/69 was published in 1978 and the energy coefficients were made available by James in 1980. As data handling procedures improve, this time lag is being progressively shortened. Energy-economic tables for 1974/75, 1977/78 and 1978/79 (James, 1982a; 1982b), though not as comprehensive as those for 1968/69 were published with less delay.

Commonly, both process analysis and input-output analysis are employed together in energy analysis.

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Opposition to Energy Analysis

As long as energy analysis is used for energy auditing purposes it has been generally welcomed as adding to the store of data available to assist in decision-making and policy-making processes. There has however, been criticism of the way in which energy from different sources is added together:

> ... a KJ of fossil fuel is not necessarily equal to another KJ of fossil fuel. A KJ of liquid fuel is worth much more to us in terms of dollars, national defence and social policy than a KJ of fossil fuel, like coal (Doering, 1980).

There has also been talk of discounting energy using the notion that a joule of energy now is worth more than a joule in the future. But these are economic arguments not thermodynamic ones. In terms of work done in driving a process, a joule of available energy from one source is identical to a joule of available energy from another and the work done is the same irrespective of when that joule is applied. This is not to say that separate account should not be kept of the different forms of energy which contribute to driving a process, for how else can the analysis contribute to monitoring depletion (or accretion!) of primary energy resources?

The suggestion, explicit or implied, that energy analysis could have normative significance, i.e. that explicit consideration should be given to energy efficiency in determining what goods to produce and their price, has been vigorously opposed by some economists (e.g. Edwards, 1976; Berndt, 1978; Lloyd, 1978). Others have been cautiously sympathetic to this view (e.g. Common, 1977). Georgescu-Roegen (1976), in his philosophical treatise "The Entropy Law and Economic Process" says (page 282-83)

> it would be utterly wrong to equate the economic process with a vast thermodynamic system and, as a result, to claim that it can be described by an equally vast number of equations patterned after those of thermodynamics which allow no discrimination between the economic value of an edible mushroom and a poisonous one.

He nevertheless holds that 'the basic nature of the economic process is entropic and that the Entropy Law rules supreme over this process and its evolution'. One or two economists have taken the extreme view that energy analysis has nothing to offer: 'energy analysis is a technique looking for a function (Webb and Pearce, 1975).

A collated reprint of articles on energy analysis from the journals of Energy Policy and Food Policy edited by Thomas (1977) provides a convenient compendium of views at the time when the fledgling energy analysis was stretching its wings.

This study is not concerned intimately with the energy theory of value, only with reckoning of energy inputs and outputs and the significance of these to the future of softwood plantation forestry in Australia.

- Chapter 1 -

Energy Analysis for Plantation Forestry

Plantations are especially important in meeting the demand for softwood in Australia. In 1982/83 exotic softwood species provided 38% of the country's sawlogs and plylogs, and 30% of pulpwood by volume (BAE,1984). By the year 2000, softwood plantations will provide twice as much sawlog as australia's native forest and about one-third of the pulpwood (Forwood, 1975, Table V). At March 31, 1983, 70% of the 774,473 ha under coniferous plantation was planted with radiata pine (*Pinus radiata*), 21% with other species (mainly *P. finaster* in Western Australia, *P. elliotii* and *P. caribaea* in Queensland), and 9% was of non-Pinus species, mainly *Araucaria.* The profile of annual planting between the 1930s and the present is similar to that in Fig. 2.1. From the late 60s, between 30,000-36,000 ha have been planted annually with exotic softwood species.

Plantation foresty consists of a number of separate operations from preparation of the site for planting to harvesting the final crop and transporting it to the mill door (or log yard of the processing plant). The age class distribution of the plantation estate being as it is, energy inputs to maintenance operations such as pruning, and to harvesting operations, must increase substantially as the estate grows in size, and as more and more trees mature at between 35-45 years old.

What are the energy inputs to the various operations of plantation forestry? What are the total energy requirements of the Australian softwood estate? What forms of energy are required? In not much longer than a rotation, petroleum fuels are expected to be in short supply.

Can plantations themselves supply energy to meet their own and national needs?

This study, which is the first full energy analysis of forestry operations in Australia, attempts to answer these questions. Basic data were gathered from a first rotation radiata pine plantation near Tumut in the southern highlands of New South Wales where silviculture and management is reasonably representative of softwood forests Australia-wide.

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Chapter Two

COLLECTING DATA FOR TUMUT SUB-DISTRICT

The Tumut Plantation

The Tumut forestry district is subdivided, for purposes of administration by the Forestry Commission of New South Wales, into three sub-districts[1] - Tumut, Batlow and Tumbarumba. At the outset of the study it was thought that data covering a number of years could be gathered from both the Tumut and the Batlow sub-districts. However, this proved impractical because of the time needed to collect, code and check the accuracy of coding of data, especially as techniques for handling data were being developed at the same time. Hence, data for only one year (1977/78) and for one sub-district (Tumut) form the basis for this study.

The Site

The Tumut forestry sub-district lies in the mountains between the township of Tumut and the valley of the Goodradigbee River west of Canberra (Figure 2.1). Along its southern edge the sub-district borders on the Kosciusko National Park. Elevation is generally above

[1] Since writing this portion of the thesis the N.S.W. Forestry Commission has had major administrative changes. One effect of this has been to change districts to regions and sub-districts to districts. However I have retained the old nomenclature since the work reported was based on the then sub-district boundaries.

1000 metres with peaks rising to 1450 metres. Soils are predominantly red earths (GN2.14, Northcote, 1971) overlying igneous parent material. Before clearing for planting, the native vegetation was mainly medium tall to tall open forest of mountain gum (*Eucalyptus dalrympleana*), sometimes with broad-leafed and/or narrow-leafed peppermint (*E. dives*, *E. robertsonii*) with scattered small stands of alpine ash (*E. delegatensis*) occurring on moist, cool sites with deep, well drained soils. *E. camphora* occupies swampy sites and snow gums (*E. pauciflora*) grow at the higher elevations. The climate, species associations and preferred aspects and altitudinal ranges described in 'Resources of the Cotter' (Anon., 1973) apply in broad terms to the Tumut sub-district. More than half the sub-district has now been planted with pines.

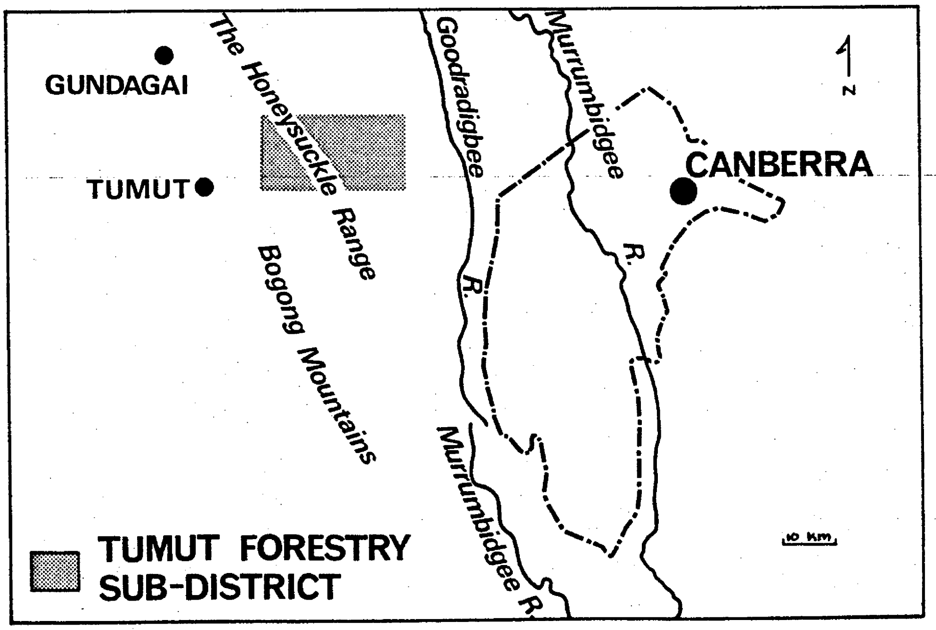


Figure 2.1 Location of the Tumut forestry sub-district

- Chapter 2 -

Plantation history

Figure 2.2 shows the number of hectares planted annually in the sub-district since 1928. Practically all the planting has been of *Pinus radiata* D.Don. A modest planting programme of less than 300 ha/yr was carried on from 1928 till 1936 when planting was suspended for 10 years. Thereafter it continued on a small scale till 1955 when the planting rate was approximately doubled. From 1967, with the exception of 1976, the planting rate has been 1000 ha or more per year. As a result of this planting pattern the oldest trees in the plantation were nearly 50 years old at the time data were gathered but the bulk of the plantation was less than 12 years old. An area of 23000 ha had been planted by June 30th, 1978.

Most of the planting in the Tumut sub-district has been on sites cleared of the original eucalypt forest. Until the 1950s, when chainsaws were introduced, clearing was done manually using axes and crosscut saws and planting was done amongst the burned remains of eucalypt trees. Bulldozers were used for clearing from about 1960 but it was not until 1971 that uprooted trees were pushed into windrows, where they could be burned more effectively, and the land between the windrows ploughed to provide a better planting site.

Plantation operations

A brief description of the nine forestry operations recognized for the purpose of this study together with work statistics for the sub-district for the financial year 1977/78 is given in Table 2.1. The four letter descriptor in the left-hand column of the table was used to represent the operations in computer analyses and in tables

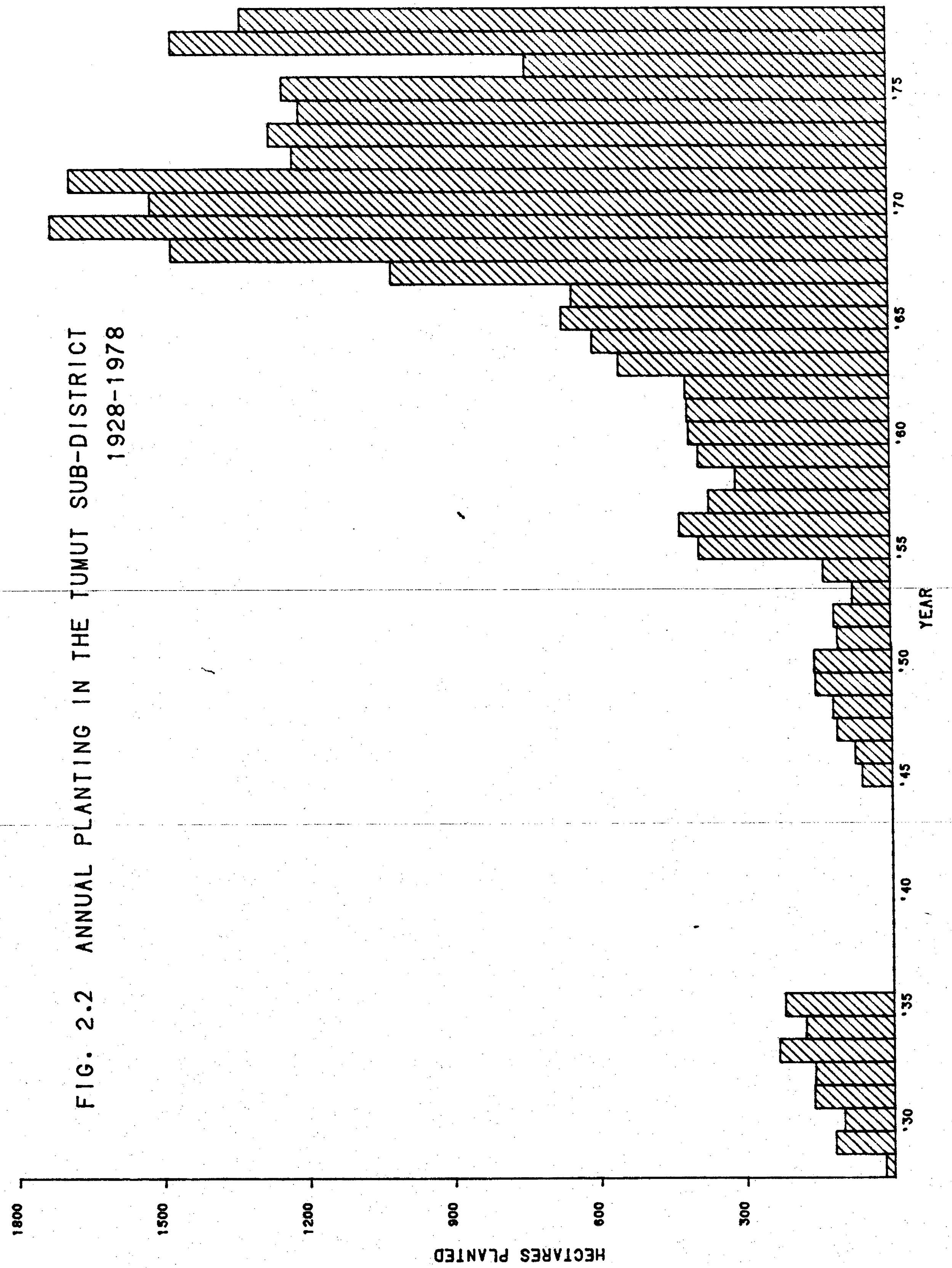


FIG. 2.2 ANNUAL PLANTING IN THE TUMUT SUB-DISTRICT
1928-1978

Table 2.1 A brief description of forest operations and work statistics for the Tumut sub-district plantation, 1977/78.

Operation	Description	Area (ha)
ROAD	New roading includes surveying, clearing, forming, draining and installing culverts, and gravelling. In 1977/78 25 km of new roading was constructed. Each kilometre is assumed to serve 38 ha.	950
MAIN	Road maintenance includes grading, minor gravelling and repairs to bitumen and drainage. In 1977/78 80 km of roads were maintained.	3000
SITE	Site preparation involves clearing native eucalypt forest with bulldozers, windrowing, burning and cultivating between the windrows using a large disc plough.	661
NURS	Nursery work includes collecting seed and raising one year old seedlings. In 1977/78 4.22 million seedlings were raised. A planting rate of 1320 seedlings per hectare is assumed.	3200
ESTB	Planting includes transport of men and seedlings to the planting site and planting by hand.	1327
TEND	Tending includes hand slashing of one year old eucalypt and three year old wattle regrowth plus non-commercial thinning of four year old pines.	2893
PRUN	Pruning involves hand saws and shears. All trees are low-pruned (to 2m) when they are 8 years old and approximately 180 final crop trees are high-pruned (to 5.5m) at age 12.5 years. In 1977/78 1303 ha were low-pruned and 215 ha were high-pruned.	1518
PROT	Protection entails protection from fire, insect and fungal attack and maintenance of capital works (excluding roads) over the total plantation area.	23473
HARV	Harvesting is by semi-mechanized means (see Appendix Figure A.1). Loading, transport for an average distance of 25 km and unloading are included in the harvesting operation. 31,457 m^3 of first thinnings, 29,316 m^3 of second thinnings, delayed first thinnings and third thinnings and 30,221 m^3 of final crop were harvested from the sub-district in 1977/78.	

and figures appearing in this thesis. Planting has always been done by hand in the Tumut sub-district and, as distinct from some districts, the application of fertilizers and herbicides has not been a feature of establishment or tending operations. Harvesting in 1977/78 was done by a combination of chainsaw felling and machine skidding or forwarding - a system nowadays sometimes termed 'motor-manual'. The harvesting operation was later divided into three sub-operations, viz. felling, snigging and hauling. These are described and energy inputs separately calculated in Chapter 4.

Plantation production

Data on biomass production from the Tumut sub-district plantations are needed for calculations of theoretical energy outputs described in Chapter 5. Foresters generally measure production in terms of volume of wood added on to the merchantable boles of trees (butt to 10 cm diameter point). Volume increment varies according to such factors as site, spacing of trees, thinning intensity and age of the plantation. Sixteen (16) cubic metres per hectare per year is often quoted as a rule-of-thumb increment for Tumut plantations but the more detailed analysis of production given in Table 2.2 suggests the annual increment on the merchantable boles may average slightly more than 17 m^3/ha over a 40 year rotation (equivalent to about 10 tonnes (air-dry)/ha.yr).

A more precise estimate of plantation production can be obtained by actually weighing biomass - the mass of living plant matter. This method is little used as it is extremely tedious. However, Forrest & Ovington (1970), working in an age series of radiata pine in the Billapaloola plantation of the Tumut sub-district, have estimated the maximum production of above-ground organic matter to be 22.5 tonnes (oven-dry)/ha.yr (approximately 25.9 t (air-dry)) between ages 5 and 7 years. This is for a plantation at approximately standard spacing, i.e. 2.4 m x 2.4 m (1700 trees/ha), and includes all above-ground plant parts. By this stage practically all biomass is in the trees; grasses and herbs having been suppressed. Bolewood growth is 10.9 t (air-dry)/ha.yr between these ages, rising to a maximum of 15.6 t (air-dry)/ha.yr between ages 7 and 9 and then falling off again to 12.4 t between ages 9 and 12 years. Forrest (1973) combines data from other replicated field experiments in southern New South Wales with that from Billapaloola from which it can be calculated that total bolewood production between ages 10 and 20 years averaged 16.0 t (air-dry)/ha.yr and, extrapolating from Forrest's figures, 14.4 t between 20 and 25 years, 13.7 t (25-30 years), 11.5 t (30-35 years), 11.7 t (35-40 years) and 9.8 t (40-45 years) for thinned plantations. The mean annual bolewood increment when the forest is managed for maximum wood production over a rotation of 40 years works out at 10.8 t (air-dry)/ha. Allowing that merchantable bole is about 95% of total bole this is the same rate of production as derived in Table 2.2.

Forrest (1969) quotes from a number of studies to argue that about 16% of the total biomass in a radiata pine plantation (i.e. 19% of the above-ground biomass) comprises stumps and roots greater than 0.5 cm diameter. While below-ground parts were not measured in the Billapaloola plantation, Forrest & Ovington (1970), extrapolating from the finding that the weight of the stumps and roots greater than 0.5 cm in diameter in an eight year old stand of radiata pine growing near Canberra was about 15% of total tree weight, suggest that by age 12 years there might be of the order of 22.5 t/ha of woody material underground, i.e. a mean annual growth rate of 22.5/12 = 1.9 t/ha.

Table 2.2 Yield per hectare of radiata pine merchantable boles from the Tumut sub-district over a rotation of 40 years.

(Source: Forestry Commission, N.S.W.)

Age (yr)		Product	Yield (m^3) u.b.	(t) green	(t) air-dry wood	bark
13	T_1	pulplogs	75	86	31.7	5.1
19	T_2	pulplogs	30	34	12.7	2.1
		sawlogs	50	56	27.3	3.3
25	T_3	sawlogs	70	78	38.1	4.6
30	T_4	sawlogs	70	78	38.1	4.6
35	T_5	sawlogs	70	78	38.1	4.6
40	CF	sawlogs	330	367	179.9	22.0
			695	777	365.9	46.3

Notes

T_1, first thinning; T_2, second thinning, etc.; CF, clearfall; u.b., under bark

Conversion from volume to green mass:
pulplogs 1m^3 (u.b.) = 1.142 tonnes incl. bark
sawlogs 1m^3 (u.b.) = 1.112 tonnes incl. bark

Conversion from green mass to air dry mass:
pulplogs @ 150% moisture content*
to wood @ 15% m.c. multiply by 0.37
to bark @ 15% m.c. multiply by 0.06
sawlogs @ 98% m.c.
to wood @ 15% m.c. multiply by 0.49
to bark @ 15% m.c. multiply by 0.06

* Moisture content is expressed throughout the thesis as a percentage of the oven-dry mass of woody fibre material. The relationship between the moisture content on this basis (odm) and the moisture content on a wet mass basis (wm) is given by the formula:

$$\text{m.c.(wm)\%} = \frac{\text{m.c.(odm)\%}}{100 + \text{m.c.(odm)\%}} \times 100$$

Thus 15%(odm) is equivalent to 13%(wm) and 100%(odm) = 50%(wm)

- Chapter 2 -

Collecting Data for Calculating Energy Inputs

Data needed to calculate inputs of energy for growing and harvesting radiata pine in the Tumut sub-district were obtained from the Forestry Commission, three logging contractors and a clearing contractor. One logging contractor was engaged on first thinning, another harvested mainly final crop trees and the third combined thinning with clearfelling. Data obtained from the Forestry Commission, one logging contractor and the clearing contractor were specifically for the financial year 1977/78. Data from the other logging contractors reflected current annual energy use at the time of the interviews in May, 1979.

Sufficient data were collected to compute energy inputs to each of nine forestry operations (see Table 2.1) in the following five input categories: fuel and lubricants for machines (fuel), repairs and maintenance of machines (repairs), machine manufacture (steel), goods and services (goods), and human labour (labour). Abbreviated names for subsequent identification of these categories are given in brackets. Data to calculate energy expended at the *district* level, as distinct from the *sub-district* level, e.g. for research, district officer travel and fire control, were also collected. Some of the district energy expenditure was apportioned to the Tumut sub-district in the ratio of sub-district expenditure (monetary) to total district expenditure (1:2.7 in 1977/78).

All tasks carried out by Forestry Commission employees or machines, and all goods and services purchased by the Commission are charged against standard job numbers (from the 'Standard Job List' current in 1978) as part of the Commission's accounting procedure.

Practically all items charged against the district and sub-district accounts in 1977/78 and some that were not so charged (e.g. electricity) were recorded, together with job numbers, on computer data forms. These data were converted to machine-readable code and, after data and format had been checked for accuracy, stored on magnetic tape. Data gathered from contractors were similarly recorded. Job numbers were allocated to one or other of the nine forest operations described above or consigned to 'overheads' to be redistributed among forest operations as indicated later. Initially a category 'other' was reserved for job numbers not fitting into any of the operations or into overheads. The computer files which list job numbers against operations were revised to absorb any of these job numbers where this was appropriate, otherwise data were deleted, for instance because they applied to localities other than the Tumut sub-district or concerned hardwood operations. A list of major data files as well as programme files compiled during the study appears in Appendix Table A.1. One-page examples of data files and some of the programmes written to compute from these data sets are bound with this thesis. Data can be made available on request.

The following notes specify what data were gathered and how they were acquired.

Plant and vehicles in use

The number and types of machines, whether powered or not, working in the Tumut sub-district, and the distances travelled or hours worked on different jobs in the period July 1977-July 1978 were obtained from fortnightly returns of the Forestry Commission and from contractors' records. Wages employees of the Forestry Commission used a car pool to get to work: it was assumed that 12 passenger vehicles travelled a total of 50 km each day from the township of Tumut to the plantation and back. Cutters and harvesting plant operators generally drove their own private vehicles to work. A one-page example of the data record appears as Appendix Table A.2. Plant and vehicles were given codes as far as possible conforming with those adopted by the N.S.W. Forestry Commission or, if a machine was of a type not coded by the Forestry Commission, the Commonwealth Department of Housing and Construction code. For a list of the plant codes used see Appendix Table A.5.

Consumption rate of fuel, oil and grease

A number of people of various organizations (see Acknowledgements) were consulted to compile Appendix Table A.3 which shows rates of consumption of petroleum products by different machine types. The same machines working under different loads and on different terrain use fuel, oil and grease at different rates; however, a rate had to be chosen for average operating conditions since details of the machines operating environment were not available. Generally operations were in hilly to mountainous terrain with mainly gravel roads leading downhill to wood processing plants. Figures for consumption of diesel fuel, oils and grease for most heavy machines were taken from the Caterpillar Performance Handbook (Caterpillar, 1978), using figures for medium loading, except in the case of front-end loaders used for loading and unloading logs when the load factor was considered to be low. Fuel consumption rates for Forestry Commission machines calculated from fortnightly running returns were incorporated into the table where they were means of 10 or more records. Later, figures became available from the Forestry Commission for fuel consumption by the various machine types in their fleet, based on fuel returns for three months from all districts. These figures did not always tally well with those from Appendix Table A.3 perhaps because of differences in terrain and/or road standards. These data were not necessarily representative of Tumut so it was decided not to amend the table since it was already reasonably soundly based.

Repairs and maintenance to machines

Records of the dollar costs of all repairs and maintenance, and of tyre replacement alone, are kept by the Forestry Commission for each machine in its fleet, both for the current year and for the life of the machine. Information from these records for repairs to the Tumut machines is set out in Appendix Table A.4. Where a particular machine type used in Tumut was not represented in the Commission records the table was completed by drawing on contractors' estimates of repair costs and estimates from other sources (see Acknowledgements). Direct and indirect energy association with each dollar value of tyres and workshop repairs can be found using the input-output matrix approach described earlier.

Steel in machines

A certain amount of energy is embodied in the steel and manufacture of machines. Appendix Table A.5, which is compiled from various sources (see Acknowledgements), lists the tare weight and life expectancy for each machine type, enabling the mass of machine 'consumed' per unit time or distance to be calculated. Energy per unit mass coefficients are given in Chapter 3.

Goods and services

Just as energy is embodied in machines, direct and indirect energy is used in goods and services. Data obtained from the Forestry Commission included all goods and services purchased in the year 1977/78, but information volunteered by contractors refers to current annual consumption of major items only and is therefore likely to underestimate the total goods and services used. Information on both quantities and dollar values of all goods and services was gathered and the goods and services classified according to the Australian Standard Industrial Classification (ASIC) (CBCS, 1975). A one-page example of the data record is shown as Appendix Table A.6.

Electrical energy (considered a service) used in the sub-district and in the district office did not appear in the Commission records but was obtained from records of the Tumut County Council. 1770GJ were used in 1977/78.

Human labour

Manhours worked in the Tumut sub-district and in the district in 1977/78 were obtained from fortnightly wage returns for forestry workers and by estimating hours worked by cutters and other contractors and salaried officers of the Forestry Commission. A one-page example of the data record is shown as Appendix Table A.7.

The detailed records kept by the state forestry authorities - in this case the Forestry Commission of New South Wales - provide opportunities for energy analysis unrivalled in other primary industries.

However, there are problems of handling the huge amount of data: computer management is essential. Data was managed broadly in a matrix of 9 operations by 5 types of input to each operation. Regrettably the time taken to gather it was such that data for only one year were recorded, but the methodology is now established for handling larger data sets in a similar analytical frame. It should be possible in future to gather data for energy analysis more readily since the required information is recorded in computer-compatible form or even entered directly onto computer storage.

Chapter Three

ENERGY USED IN GROWING AND HARVESTING A FIRST ROTATION RADIATA PINE PLANTATION

Computing Energy Inputs to the Tumut Plantation, 1977/78

Energy expended in each plantation operation in the Tumut sub-district in 1977/78 was calculated for five input categories using programme/data combinations shown in Appendix A.1.

Energy for operations other than harvesting

Energy always included direct energy (e.g. in liquid fuel used) and indirect energy (e.g. energy to make fuel available, energy sequestered in vehicles). Energy which could not readily be allotted to any of the nine operations was generally put into a category 'overheads' and re-distributed among non-harvesting operations in proportion to the energy used in those operations. One exception to this - allocation of the energy equivalent of petrol used to transport men to and from work - is noted in the next section. Some notes on computation within each input category are given below. Full computational details are contained in the relevant programme files included as Appendix A.18.

i) fuels and lubricants (fuel)

From a knowledge of distance travelled or hours worked by various machine types and using the rates of consumption of fuels and lubricants given in Appendix Table A.3, the quantities and energy equivalents of petrol, diesel, lubricating oil and grease used in each operation could be computed (Appendix Table A.8). The energy equivalent of petrol used to transport men, other than cutters, to and from work was first allocated to 'overheads' then distributed among plantation operations in proportion to manhours worked in each operation. The energy equivalent of diesel, lubricating oil and grease in overheads was distributed in proportion to actual consumption of these in each operation.

Indirect energy in refined petroleum products was taken to be 12% of the direct energy equivalent of fuels and lubricants, i.e. direct plus indirect energy = 1.12 x direct energy. Use of this figure is supported by Department of Resources and Energy (1983a) which indicates that 3.8 million tonnes oil equivalent (MTOE) was required in conversion of 30.8 MTOE of petroleum fuels in 1981-82 i.e. 12%. It might have been expected that the conversion figure in 1977-78, the year under consideration, would be somewhat in excess of this since refinery technology is constantly improving, but, according to a report on oil refining technology in Australia (Department of Resources and Energy, 1983b), energy used in refining crude oil in 1977-78 was approximately 10% of energy in marketable oil products. Since marketable oil products include chemical feedstocks as well as lubricating oils and petroleum fuels, it seems reasonable to adhere to the figure of 12%. Department of Resources and Energy (1983a) forecasts that energy requirements for oil conversion will drop to 10.6% of energy in petroleum fuels by 1991-92.

ii) repairs and maintenance of machines (repairs)

The input-output matrix approach was used to estimate energy used in plant and vehicle repairs and in tyres used in the sub-district in 1977/78. The figures below are cumulative energy equivalents, that is direct plus indirect energy per dollar value, for the industrial sectors 'repairs to motor vehicles' (ASIC 48.02) and 'rubber goods' (ASIC 34.02) from James (1980).

repairs (parts and labour)	64.86 MJ/$A(1968)
tyres	61.95 MJ/$A(1968)

These figures have been compiled from the 1968/69 national accounts: in applying these to find the energy equivalent of repairs and goods and services (see below) purchased in 1977/78 it must be assumed that the amount of energy embodied per constant dollar has remained unchanged. This may not be true, for, as Kashkari (1978) argues:

> Energy has been very cheap compared to other goods and services with the result that sufficient care was not exercised in using it. That situation has changed. As the price of energy goes up, every effort will be made to reduce the consumption of energy to a minimum, but in the process the values and the coefficients will change. However, once the energy processes reach an optimum level of efficiency, the coefficients will stabilize at some fixed value.

James shows that, overall, primary energy used in Australia per dollar value of gross domestic product remained almost constant between 1968 and 1976, however this says nothing about fluctuations which may have taken place in energy coefficients within sectors. Energy-economic tables have been compiled for 1977/78 (James *et al*, 1982b) but industrial sectors have had to be aggregated into 49 super-sectors because energy input data were not available separately for each of the 109 sectors recognised in the Australian national accounts. This has meant that energy coefficients are so unspecific in some cases as to be almost meaningless; for instance, energy in 'repairs to motor vehicles' has been lumped together with that in 'wholesale and retail trade' and 'other repairs' and energy in 'rubber goods' has been lumped with that in 'miscellaneous manufacturing'. For this reason and for the reason that energy cannot be traced back to primary sources using the tables for 1977/78 (see later section), energy coefficients have been taken from the compilation based on 1968/69 data.

Where particular machines could be identified by their Forestry Commission numbers, repairs energy specific to 1977/78 could sometimes be computed; otherwise calculation of repair energy was based on mean annual repair costs and costs of tyre replacement over the lives of machines (Appendix Table A.4).

Energy in tyres is shown separately from energy in workshop repairs (parts and labour) in Appendix Table A.9, but these are combined under 'repairs' in Table 3.1.

iii) goods and services (goods)

The energy embodied in goods and that required to provide services has been computed using figures derived by process analysis where these are available (Appendix A.10). Where two or more values are shown for a product, the simple arithmetic mean value was used. Otherwise figures from James (1980) for cumulative energy per dollar value for the appropriate industry sectors were used.

Energy used directly in the form of electricity (467 GJ in 1977/78) was multiplied by 3.79 to account for indirect energy for generation and supply (Saddler & Davies, 1979) and the resulting direct plus indirect energy distributed, together with overheads, amongst forest operations. The enthalpy of combustion of the bottled gas used (15.7 GJ) was multiplied by 1.10 to account for indirect energy (Gartside, 1975) and the resulting direct plus indirect energy distributed between nursery and pruning operations where Commission records indicated the gas was used. Actually most of the gas was used for heating and cooking but since nursery and pruning are the most labour intensive operations its allocation to these operations is reasonable.

iv) machine manufacture (steel)

Coefficients used to calculate energy embodied in the steel and manufacture of machines 'consumed' in the sub-district in 1977/78 were the same as those used by Handreck and Martin (1976) from Berry and Fels (1972), viz.

tractors, vehicles, powered machinery	88.3 MJ/kg
other machinery	65.7 MJ/kg

Blankenhorn *et al.* (1978) used coefficients almost twice these but Smith and McChesney, in a supplement to Dawson (1978), contend that the values of Berry and Fels are better substantiated than the figures of Roller *et al.* (1975) which were used by Blankenhorn *et al.* Figures of 84.8 MJ/kg for car manufacture, 75 MJ/kg for trucks and 80 MJ/kg for tractors derived by Croke (1980) are similar to those for powered machinery given above.

Table 3.1 Direct and indirect energy expenditure (GJ), Tumut sub-district 1977/78. Figures in brackets are percent of total. (See Figure 3.1).

	FUEL	REPAIRS	GOODS	STEEL	LABOUR	TOTAL
ROAD (24)	7693.5 (50)	2965.7 (19)	3311.0 (22)	1053.1 (7)	212.4 (1)	15235.7 (100)
MAIN (5)	1869.5 (57)	697.7 (21)	404.7 (13)	192.4 (6)	81.5 (3)	3245.8 (100)
SITE (13)	5621.3 (67)	1644.0 (20)	227.7 (3)	852.5 (10)	26.9 (-)	8372.4 (100)
NURS (2)	653.9 (44)	56.0 (4)	638.9 (42)	30.4 (2)	124.6 (8)	1503.8 (100)
ESTB (1)	554.2 (66)	108.6 (13)	20.6 (3)	46.9 (6)	105.3 (13)	835.6 (100)
TEND (1)	527.3 (68)	74.6 (9)	45.6 (6)	22.1 (3)	110.2 (14)	779.8 (100)
PRUN (5)	2262.5 (67)	272.8 (8)	253.0 (7)	77.7 (2)	536.5 (16)	3402.5 (100)
PROT (3)	948.1 (48)	342.2 (18)	452.8 (23)	143.4 (7)	73.2 (4)	1959.7 (100)
HARV (42)	21248.2 (75)	3915.9 (14)	102.1 (1)	2247.4 (8)	715.1 (3)	28228.8 (100)
TOTAL (100)	41378.5 (65)	10077.5 (16)	5456.5 (9)	4665.9 (7)	1985.7 (3)	63564.1 (100)

Notes

Goods include 17.3 GJ bottled gas and 1770 GJ electricity.

v) human labour (labour)

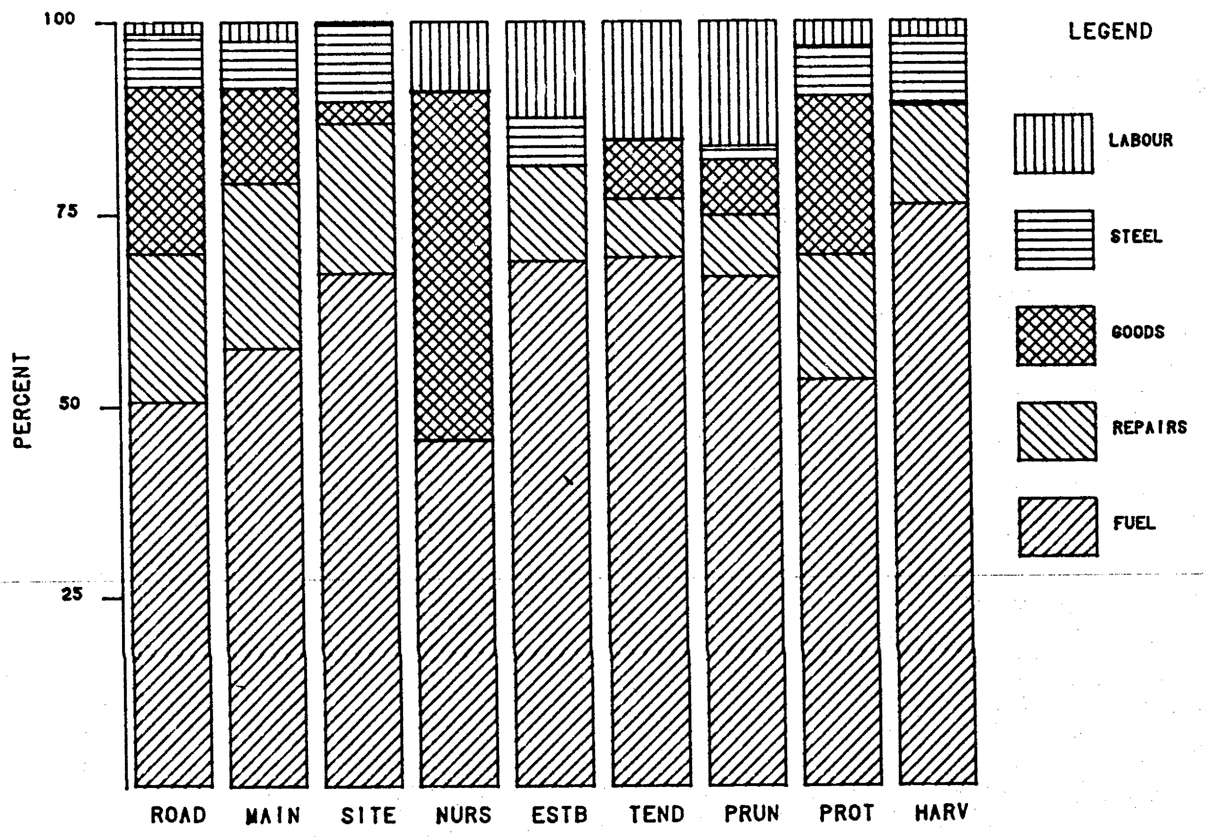
Energy of human labour per eight hour shift has been equated with the direct and indirect energy of two-thirds of the average daily food intake. This adopts the simplistic argument of equating food digested on the job with fuel used by machines. It has been calculated that an average daily Australian diet has a calorific value of 13.664 MJ but this figure must be multiplied by 6.8 to account for the indirect energy inputs to growing, harvesting, transporting, packaging, storing and preparing food (Watt, 1979). Energy of human labour has therefore been counted as 7.7 MJ/hr. The figure used by Blankenhorn *et al.* (1978) was 1.34 MJ/hr and by Gifford and Millington (1975) less than 1 MJ/hr but these estimates did not include indirect energy sequestered in food. Calculations based on (a) treating a person as an energy converter, (b) measuring actual work output and (c) considering energy residual after subtracting metabolic energy requirements, all give figures around 200 KJ/hr (Smil, 1980).

It might be argued that energy of human labour is undervalued using the above approaches. Norum (1983) reports that a Swedish working group calculated that, if all energy use in society is viewed as input required to maintain human capacity for work, 108 MJ/hr would be attributable to human labour in Sweden in 1956 and 234 MJ/hr in 1972. Using a similar argument, but working through national energy requirements per gross domestic product and individual incomes, Novis (pers. comm.) placed an energy value on labour in New Zealand in 1980 of 89-157 MJ/hr. This approach is not tenable when the dangers of double counting are considered. As Casper *et al.* (Norum, 1983) have said:

> If energy used to produce goods and services consumed by households is included as inputs to the industry for which members of the family work, the same energy will have been counted twice, first as input to the production process, secondly as labour input when the product is consumed.

The Swedish working group, Norum, and Casper *et al.* all recommend against using an energy value for labour, preferring instead to quantify labour input in hours. As stated in Chapter 2, manhours worked in each operation in Tumut plantations were recorded; estimates in these units

FIG. 3.1 PERCENTAGE CONTRIBUTION OF ENERGY INPUT CATEGORIES TO DIFFERENT OPERATIONS



can be retrieved from tables of energy consumption by dividing labour energy input figures by 7.7×10^6.

Results are included in Table 3.1 and Figure 3.1.

Energy for harvesting

In order to arrive at the best estimate of the energy required to harvest radiata pine logs from the Tumut sub-district in 1977/78 the energy used by each logging contractor per tonne of green logs was computed. The energy inputs were divided into five categories as for non-harvesting operations. Since one contractor was engaged on harvesting pulplogs from first thinnings, another in harvesting a mixture of pulplogs and sawlogs mainly from second thinnings, and the third harvested sawlogs only, mainly from the final crop, this gives a measure of the energy required to harvest different classes of logs. Estimates of energy used for supervision by the staff of the Forestry Commission have been added in Table 3.2 and the energy requirements shown graphically in Figure 3.2. It can be seen that less energy per tonne is required to harvest the larger sawlogs than for the smaller pulplogs. All three logging contractors were using motor-manual techniques (see Appendix Figure A.1).

The figures for harvesting energy given in Table 3.1 were obtained by applying the rates of energy consumption shown in Table 3.2 to the 1977/78 sub-district cut of 90,994m^3 which consisted of approximately one-third of pulplogs from first thinnings, one-third mixed pulplogs and sawlogs from later thinnings and one-third sawlogs from the final crop (Table 2.1). The quantities and energy contents of oil-derived products shown for harvesting in Appendix Table A.8 were similarly derived from data in Appendix Table A.11.

Table 3.2 Direct plus indirect energy required for harvesting radiata pine in the Tumut district (MJ per tonne of green logs).

	Pulplogs Only[a]			Mixed[b]			Sawlogs Only[c]		
	Con	FC	Total	Con	FC	Total	Con	FC	Total
FUEL#	267	2	269	209	2	211	142	2	144
REPAIRS	48	2	50	41	2	43	20	2	22
GOODS	1	-	1	1	-	1	1	-	1
STEEL	27	-	27	22	-	22	17	-	17
LABOUR	9	-	9	9*	-	9	3	-	3
TOTAL	352	4	356	282	4	286	183	4	187

Notes

Energy per tonne is based on cutting, snigging (or forwarding), loading hauling and unloading

a 31,412 tonnes pulplogs (first thinning),

b 40,606 tonnes sawlogs and 14,466 tonnes pulplogs, i.e. a ratio saw:pulp = 2.8:1 (mainly second thinning),

c 69,930 tonnes sawlogs (mainly final crop),

some of which came from outside the Tumut sub-district but from within the Tumut district.

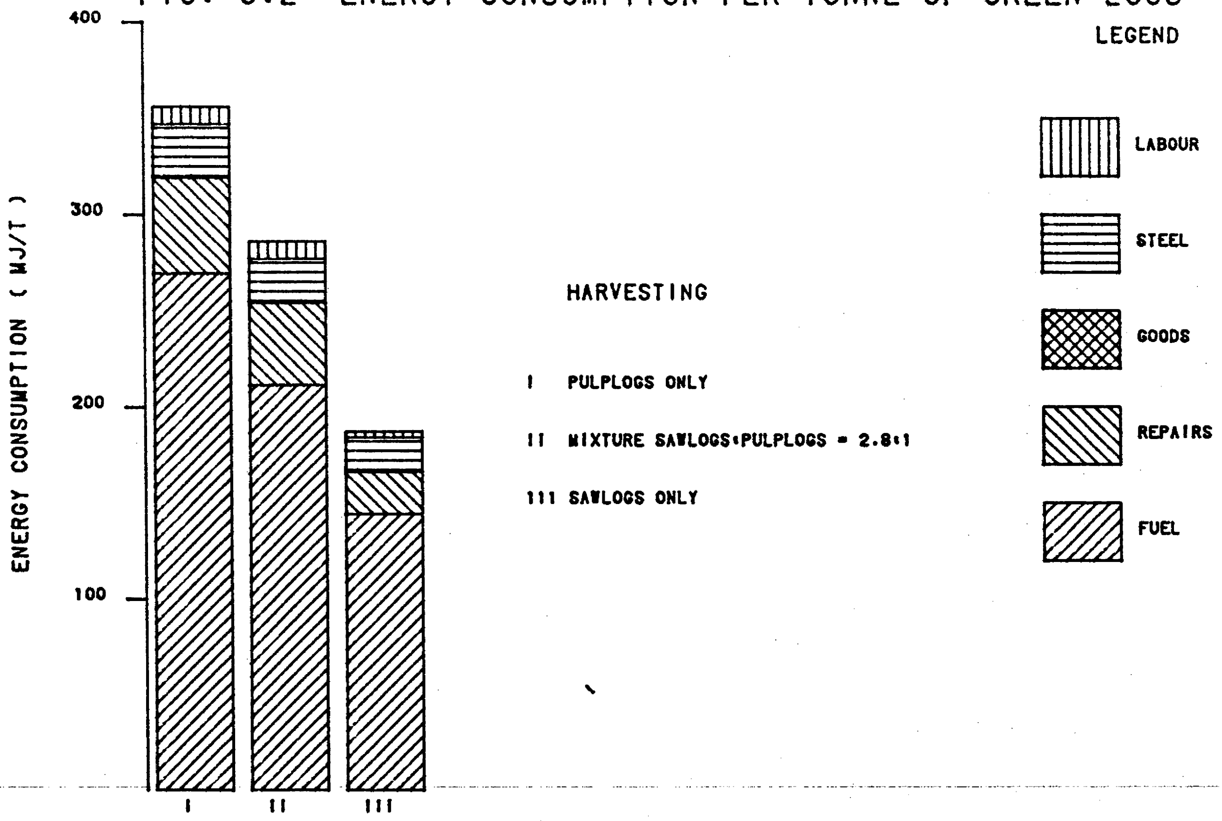
Con = Logging contractor

FC = Forestry Commission of New South Wales

* includes an additional 947 tonnes of pulpwood which was cut only (not snigged or hauled),

\# for breakdown by fuel type see Appendix Table A.11.

FIG. 3.2 ENERGY CONSUMPTION PER TONNE OF GREEN LOGS



Energy Requirements for a Forty Year First Rotation

Table 3.1 shows energy used in the Tumut sub-district by input categories and forest operations for one year only, 1977/78. We need to know how much energy is used to grow and harvest a pine plantation over a whole rotation.

The Tumut sub-district plantation is not yet managed as a 'normal' forest, i.e. one in which the area planted and the area harvested each year, and from year to year, is the same so that each age class occupies a similar area of forest throughout the rotation. As can be seen in Figure 2.2, the area established each year has fluctuated; hence the annual energy requirement for each operation is not constant. The energy expenditure found for 1977/78 cannot be used *per se* as an annual requirement over the whole rotation. An estimate of this is necessary so that results of this study can be compared with others and for forecasting the future energy needs of the plantation estate. Rates of energy expenditure per hectare derived from figures in Table 3.1 and work statistics from Table 2.1 (Table 3.3) can be substituted in a model of plantation operations to arrive at estimates of energy required over a full rotation.

Table 3.3 Per hectare energy consumption (MJ) by operations and in terms of five energy input categories, Tumut sub-district pine plantations 1977/78.

	FUEL	REPAIRS	GOODS	STEEL	LABOUR	TOTAL
ROAD	8099	3122	3485	1108	224	16038
MAIN	623	233	135	64	27	1082
SITE	8504	2487	344	1290	41	12666
NURS	204	17	200	10	39	470
ESTB	418	82	15	35	79	629
TEND	182	26	16	8	38	270
PRUN	1490	180	167	51	353	2241
PROT	41	15	19	6	3	84
HARV (per tonne green logs)						
pulplogs	269	50	1	27	9	356
mixed[a]	211	43	1	22	9	286
sawlogs	144	22	1	17	3	187

<u>Note</u>

a ratio sawlogs:pulplogs = 2.8:1

Model

Table 3.4 very simply models the forestry operations which would be involved in a 40 year first-rotation plantation. Calculations of energy requirements per hectare on a per annum basis shown in the table assume that energy inputs to operations throughout the rotation are at rates found for Tumut in 1977/78. Some operations are carried out only once in a rotation, so the values for energy expenditure per year can be calculated by dividing figures in Table 3.3 by the number of years in the rotation (40); others, such as road maintenance, may be carried out a number of times during the rotation. The energy requirements for new roading and site preparation have been costed wholly to the first rotation. It might be argued that the energy used in these operations should be spread over the life of the plantation; however, the life of the plantation is unknown and, in any case, separate analyses will be necessary for second and subsequent rotations. The yield of logs assumed for the first rotation is from the schedule of thinning reported in Table 2.2.

Energy requirements per operation

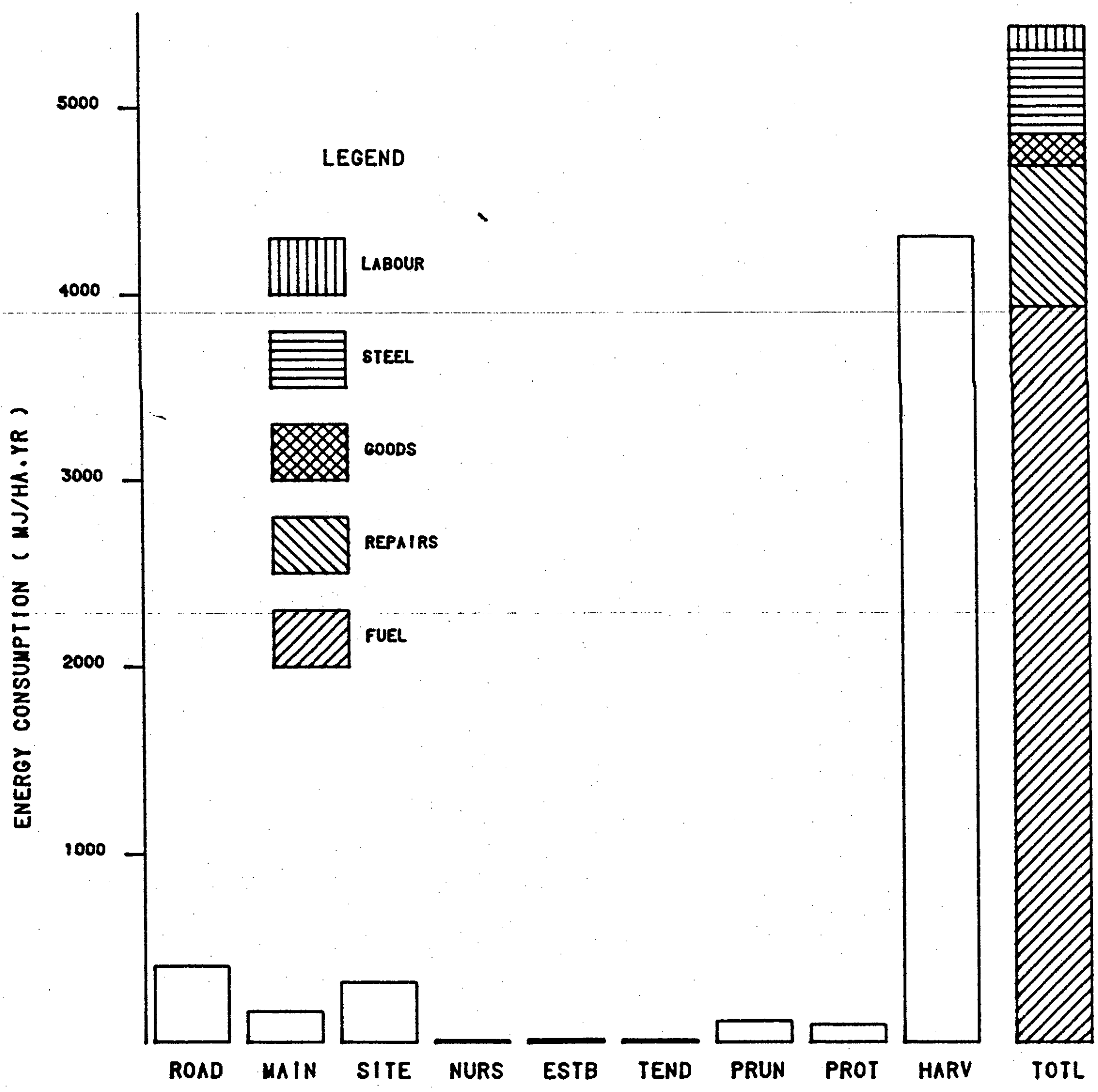
The model suggests that 5429 MJ of energy are required per hectare per annum to grow and harvest a first-rotation plantation of radiata pine. Nearly four-fifths of this energy (4312 MJ/ha.yr) is required for harvesting. Energy for new roading is next, followed by site preparation, road maintnenace, pruning and protection.

Table 3.4 Model of plantation operations over a 40 year first rotation showing energy requirements per hectare per annum.

Operation	Per rotation	MJ/ha.yr
ROAD	once	16038/40 = 401
MAIN	six times	1082 x 6/40 = 162
SITE	once	12667/40 = 317
NURS	once	470/40 = 12
ESTB	once	629/40 = 16
TEND	twice	270 x 2/40 = 13
PRUN	twice	2241 x 2/40 = 112
PROT	annually	= 84
Sub-total		1117
HARV		
pulplogs	86 tonnes	86 x 356/40 = 765
mixed	130 tonnes	130 x 286/40 = 929
sawlogs	560 tonnes	560 x 187/40 = 2618
		4312
Total Energy Consumption		5429

The nursery operations, plantation establishment, and tending, require relatively little energy. The magnitude of energy required for harvesting compared with that for other operations is highlighted in Figure 3.3. The final bar shows the contributions of the different energy input categories to the total energy requirement.

FIG. 3.3 ANNUAL ENERGY CONSUMPTION PER HECTARE FOR DIFFERENT OPERATIONS



Energy by input categories

Energy for growing and harvesting a first rotation has been split into input categories in Table 3.5 assuming that the energy expended in each operation was divided by input category in the same ratio as it was for the Tumut sub-district in 1977/78 (Table 3.1 and Figure 3.1). Differences in totals between Table 3.4 and Table 3.5 are due to rounding.

Table 3.5 Anticipated energy requirements (MJ/ha.yr) by input category for a 40 year first rotation plantation of radiata pine based on management practices in the Tumut district of New South Wales. Figures in brackets are percentages of total energy expenditure.

	FUEL	REPAIRS	GOODS	STEEL	LABOUR	TOTAL
ROAD	202	78	87	28	6	401
MAIN	93	35	20	10	4	162
SITE	213	62	9	32	1	317
NURS	5	-	5	-	1	11
ESTB	11	2	-	1	2	16
TEND	9	1	1	-	2	13
PRUN	74	9	8	2	18	111
PROT	41	15	19	6	3	84
HARV	3279	555	19	367	90	4310
TOTAL	3923 (72)	757 (14)	168 (3)	446 (8)	127 (2)	5425 (100)

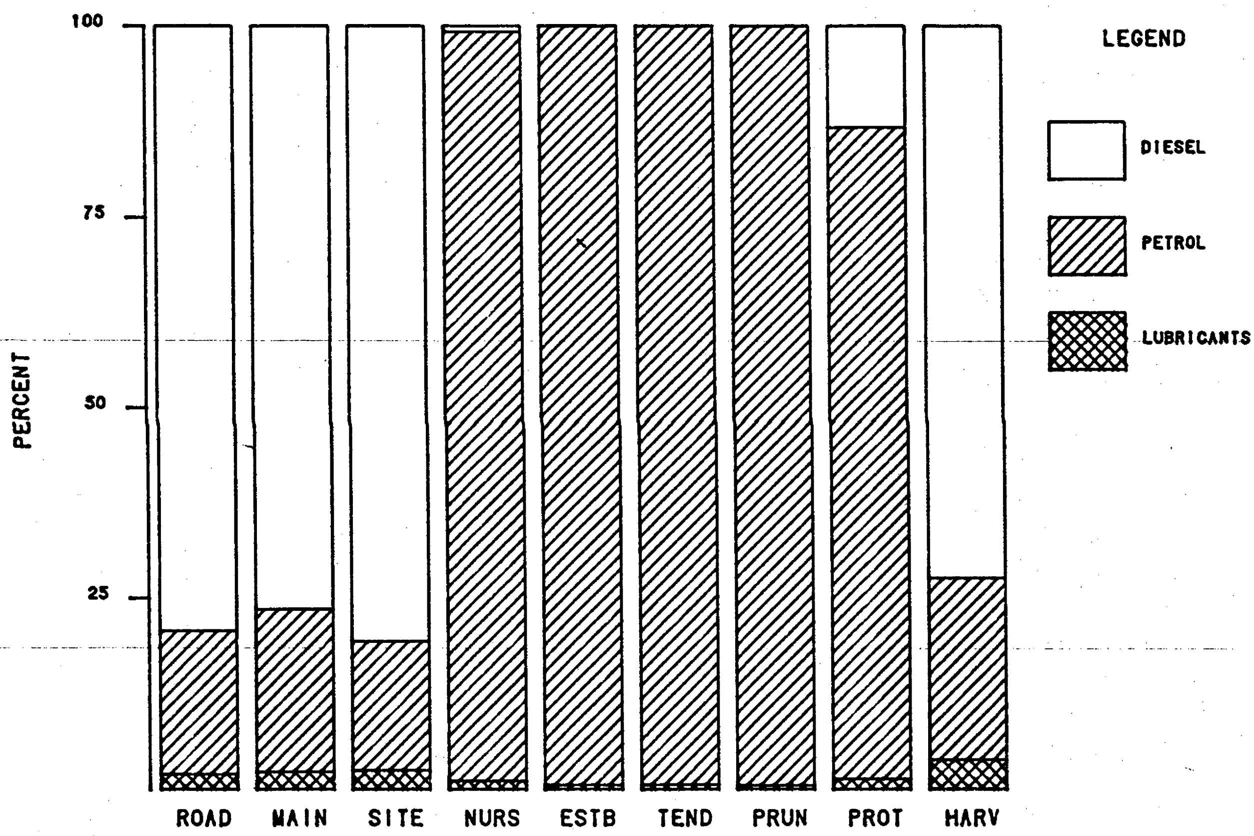
(i) fuel

Nearly three-quarters of the total energy required to grow and harvest a first rotation radiata pine plantation is needed in the form of fuel and lubricants for machines. Assuming the pattern of fuel use is the same as for 1977/78 (Fig. 3.4 and Appendix Table A.8), the requirement for petrol and diesel for different operations is as shown in Table 3.6. A total of 26 litres of petrol and approximately 65 litres of diesel is required annually per hectare. Harvesting accounts for 77% of the petrol and 85% of the diesel requirements. Although pruning is a manual operation, the requirement for petrol for this operation is higher than for any other except harvesting, reflecting the high energy cost of transporting men about in the forest. Furthermore it has been estimated that 200,000 litres, or about half the total petrol consumed in all operations in 1977/78, were used simply to transport men to the forest and back to their homes. Next after harvesting, in order of requirement for fuel, come the operations 'new roading' and 'site preparation'. The operations using a high proportion of diesel fuel can be identified in Figure 3.4.

Table 3.6 Petrol and diesel requirements per operation for a first rotation radiata pine plantation in the Tumut district (litres/ha.yr).

Operation	Petrol	Diesel
ROAD	1.0	3.7
MAIN	0.5	1.7
SITE	0.9	4.0
NURS	0.1	-
ESTB	0.3	-
TEND	0.2	-
PRUN	1.9	-
PROT	0.9	0.1
HARV	20.0	55.4
TOTAL	25.8	64.9

FIG. 3.4 PETROL, DIESEL AND LUBRICANTS AS PROPORTION OF TOTAL FUEL ENERGY IN EACH OPERATION, TUMUT 1977/78



(ii) repairs

A surprisingly high proportion (14%) of the total energy required to grow and harvest a first rotation radiata pine plantation is largely indirect energy sequestered in tyres and workshop repairs to machines. The requirements of different forest operations for repair energy (Table 3.7) rank roughly the same as for fuel energy. Harvesting has the greatest requirement - 522 MJ/ha.yr of a total of 725 MJ/ha.yr. Heavy, hard-working diesel machinery engaged on road building can be expected to consume energy for repairs amounting to almost 40 percent of that in the fuel used to operate the machines. By contrast, for pruning, where light petrol vehicles are used, repair energy is only about twelve percent of fuel energy.

Table 3.7 The energy requirement per operation associated with tyres and workshop repairs for a first rotation radiata pine plantation (MJ/ha.yr). Figures in brackets are percentages.

Operation	Tyres	Workshop	Total
ROAD	3.3 (4)	74.6 (96)	77.9 (100)
MAIN	4.9 (14)	30.2 (86)	35.1 (100)
SITE	2.7 (4)	59.4 (96)	62.1 (100)
NURS	- (-)	0.4 (100)	0.4 (100)
ESTB	0.1 (4)	2.0 (96)	2.1 (100)
TEND	0.2 (17)	1.1 (83)	1.3 (100)
PRUN	0.9 (10)	8.2 (90)	9.1 (100)
PROT	0.6 (4)	14.0 (96)	14.6 (100)
HARV	211.7 (41)	310.3 (59)	522.0 (100)
TOTAL	224.4 (31)	500.2 (69)	724.6 (100)

For most operations energy in tyres is a relatively small proportion of total energy in repairs. For harvesting, energy sequestered in tyres accounts for about 40% of the total.

(iii) goods

According to Table 3.5, the energy requirement associated with goods and services is greatest for roading where large quantities of explosives, gravel, concrete pipes and culverts are used. Overall, goods and services appear to require only about 3% of the total energy but, as already stated, goods and services supplied to harvesting operations have, almost certainly, been underestimated.

(iv) steel

The total indirect energy sequestered in machines is about 8% of the total energy required to grow and harvest a first rotation radiata pine plantation. Most of the energy is sequestered in harvesting machinery; next comes energy in machines used in road construction, then energy in machines used for site preparation.

(v) labour

The International Federation of Institutes of Advanced Studies (IFIAS, 1974) suggest that human energy can be ignored in energy analyses unless a labour-intensive process such as subsistence agriculture is being analysed. Table 3.5 shows the proportion of energy attributable to human labour to be relatively high for planting, raising seedlings, tending and pruning but insignificant overall - only about 2% of the total energy required for a first rotation. It must be recalled, however, that the calculations of energy of human labour are based on the narrow concept of man requiring only food to do work.

The computations described in this chapter indicate that about 5.4 GJ of energy is required annually to grow and harvest each hectare of a radiata pine plantation. Nearly three-quarters of this is used directly as liquid fuels and lubricants for machines.

Since energy used in harvesting constitutes so great a proportion (nearly four-fifths) of the total energy requirement, the energy inputs to component parts of this operation are examined in more detail in the next chapter.

Chapter Four

ENERGY INPUTS TO HARVESTING EXAMINED

Energy Inputs to Sub-operations of Harvesting

Three sub-operations of harvesting were recognised when gathering information on energy inputs from harvesting contractors. As already stated, one contractor was engaged in pulpwood logging only, another in logging for sawmilling only and a third in mixed logging. The sub-operations are:

(i) felling - fell trees, trim limbs, cut to length (bunch logs from first thinnings);

(ii) snigging - snig and bunch or forward[1] logs, load;

(iii) hauling - transport logs to processing plant and unload, trucks return to forest empty.

Table 4.1 shows, for each contractor, energy used for each harvesting sub-operation subdivided into the four energy input categories: fuel, repairs, steel and labour. Energy in the category 'goods' could not be apportioned among sub-operations: total goods energy used by each contractor has been dealt with in Chapter Three. Energy inputs associated with cutters and plant operators running their private vehicles to and from work in the forest, are included in the estimates.

1 A forwarder picks up and loads logs onto the rear of the machine before transporting them to the roadside.

Table 4.1 Energy requirements for logging radiata pine (MJ/tonne)

Contractor: 03 Pulplogs only

	Felling	Snigging	Hauling	Total
Fuel	107.40	55.55	110.75	273.69
Repairs	15.20	20.57	12.81	48.57
Steel	8.24	5.42	13.79	27.44
Labour	7.50	.97	.90	9.37
Total	138.33	82.51	138.25	359.08

Contractor: 04 Mixed pulplogs and sawlogs

	Felling	Snigging	Hauling	Total
Fuel	48.64	81.62	82.65	212.91
Repairs	17.64	8.54	14.86	41.05
Steel	3.24	8.15	10.33	21.72
Labour	6.85	1.74	.87	9.46
Total	76.36	100.05	108.72	285.13

Contractor: 05 Sawlogs only

	Felling	Snigging	Hauling	Total
Fuel	18.67	45.36	82.59	146.62
Repairs	5.62	5.38	9.31	20.31
Steel	1.50	4.91	10.32	16.73
Labour	1.79	.91	.41	3.11
Total	27.58	56.56	102.62	186.77

Fuel Energy

Most of the energy used by each contractor - around three-quarters of the total - was used as fuel. The total amount of fuel energy and the proportion consumed in each sub-operation were different for each contractor. About the same amount of fuel energy was used in the felling sub-operation as in the hauling sub-operation (107MJ/t cf. 111MJ/t) when harvesting pulplogs only, while considerably less (19MJ/t) was used in felling sawlogs only. The contractor harvesting a mixture of pulplogs and sawlogs used an amount of fuel energy for felling intermediate between that of the other two contractors (49MJ/t).

The considerably greater amount of fuel energy required for snigging a mixture of sawlogs and pulplogs (82MJ/t) than that required for either pulplogs only or sawlogs only (56MJ/t and 45MJ/t respectively) possibly reflects inefficiencies in using equipment optimally suited to a certain log size range to handle other log sizes.

Hauling appears to require more fuel energy per tonne for pulplogs than for sawlogs or a mixture of sawlogs and pulplogs (111MJ/t cf. 82MJ/t). This is presumably due to lower loading per journey. The ratio of tonnes carted to kilometres travelled for each contractor was

contractor	t/km
03	0.27
04	0.35
05	0.36

The amounts and types of petroleum products used in each of the sub-operations by each logging contractor in 1977/78 are shown in Table 4.2. The greatest, separately identifiable, useage of fuel energy was as petrol in felling trees for pulp (101MJ/t). The fact that fuel useage was markedly less in this sub-operation for the other two contractors (45MJ/t and 18MJ/t) reflects the greater output per cutter when felling large trees compared to smaller ones,

Table 4.2 Fuel consumption for harvesting radiata pine (per tonne green logs)

Contractor: 03 Pulplogs only

	Petrol (L)	Diesel (L)	Oil (L)	Grease (Kg)	Petrol (MJ)	Diesel (MJ)	Oil (MJ)	Grease (MJ)	All (MJ)
Fell	2.611	.000	.125	.001	101.46	.00	5.89	.04	107.40
Snig	.286	.990	.038	.004	11.11	42.45	1.80	.18	55.55
Haul	.000	2.338	.070	.006	.00	100.29	3.31	.28	103.88

Contractor: 04 Pulplogs and sawlogs

	Petrol (L)	Diesel (L)	Oil (L)	Grease (Kg)	Petrol (MJ)	Diesel (MJ)	Oil (MJ)	Grease (MJ)	All (MJ)
Fell	1.169	.000	.067	.000	45.44	.00	3.17	.02	48.64
Snig	.103	1.736	.061	.006	4.01	74.45	2.88	.29	81.62
Haul	.000	1.765	.051	.004	.00	75.69	2.39	.21	78.29

Contractor: 05 Sawlogs only

	Petrol (L)	Diesel (L)	Oil (L)	Grease (Kg)	Petrol (MJ)	Diesel (MJ)	Oil (MJ)	Grease (MJ)	All (MJ)
Fell	.457	.000	.019	.000	17.77	.00	.90	.01	18.67
Snig	.148	.876	.040	.003	5.74	37.60	1.88	.14	45.36
Haul	.000	1.750	.053	.004	.00	75.07	2.47	.21	77.75

and the cutters' use of their own private motor vehicles to travel to and from work. More cutters per unit output of logs were employed by contractor 03 than by either contractor 04 or 05.

Diesel supplied all the fuel energy used in hauling and supplied 85% and 95% of the total fuel energy for snigging sawlogs and mixed sawlogs and pulplogs respectively, and 74% of the fuel energy for snigging pulplogs.

Repair Energy

The next greatest input of energy, after fuel, is for repairs to machinery, plant and vehicles (Table 4.1). Both total expenditure of repair energy and pattern of expenditure vary considerably between contractors. Surprisingly, energy consumption for repairs in the felling sub-operation is somewhat greater (per tonne) than for hauling for two out of the three contractors. This, in part, reflects heavy energy cost for chainsaw maintenance, but it must be noted that an allowance for repairs to cutters' private vehicles is included in this sub-operation also. Repair energy for the contractor engaged in logging for sawlogs only is substantially less than for the other two because of the much greater volume (weight) of wood yielded per cut. Thus there are fewer cutters and fewer private vehicles involved.

For both the snigging and felling sub-operations more energy is expended in workshop repairs than is sequestered in tyres with one exception (Table 4.3); however, in the hauling sub-operation, energy in tyres is greater than in workshop repairs for two out of three of the contractors.

Table 4.3 Repair energy for contractors (MJ/t)

CONTRACTOR: 03 PULPLOGS ONLY

	Tyres	Parts and Labour	Total
FELL	1.2	14.0	15.2
SNIG	3.1	17.5	20.6
HAUL	4.3	8.5	12.8
TOTAL	8.6	39.9	48.6

CONTRACTOR: 04 MIXED PULPLOGS AND SAWLOGS

	Tyres	Parts and Labour	Total
FELL	0.7	16.9	17.6
SNIG	7.3	1.3	8.6
HAUL	11.4	3.5	14.9
TOTAL	19.4	21.7	41.1

CONTRACTOR: 05 SAWLOGS ONLY

	Tyres	Parts and Labour	Total
FELL	0.3	5.3	5.6
SNIG	1.8	3.5	5.4
HAUL	7.1	2.2	9.3
TOTAL	9.2	11.0	20.3

Steel Energy

Less than ten percent of the total energy consumed by each contractor is in the steel and manufacture of machines, mostly in trucks used in the hauling sub-operation (Table 4.1). For one contractor - contractor 03, pulplogs only - steel energy for felling was higher than for snigging, again reflecting heavy use of private vehicles for transport to and from work. For the other two contractors, steel energy for snigging was twice that for felling. This is not surprising considering the much heavier equipment used for snigging.

Labour Energy

Energy of human labour accounted for 5% of the total energy used for felling pulplogs only (Table 4.1). Although contractor 04 expended somewhat less labour energy, the proportion of the total energy used in felling was higher (9%). Six percent (6%) of the energy used by contractor 05 for felling was contributed by human labour. The contribution was negligible (less than 2%) in other sub-operations for all three contractors.

Factors Influencing Harvesting Energy

Increasing Mechanization

A semi-mechanized (motor-manual) system of harvesting, employing men with chainsaws to fell the trees and a forwarder or snigger to move logs to the roadside, was in use in Tumut at the time data were gathered. Recently, with a pulpmill and a chipboard factory taking wood from the plantation, a mechanized system (feller-buncher and log processor) has been introduced. The basic differences in the two systems are illustrated in Appendix Fig. 1. Gasslander *et al.* (1979), who studied the energy requirements of a mechanized and semi-mechanized system in mixed Scots pine (*Pinus sylvestris*) - spruce (*Picea abies*) forest in Sweden, show that three to four times as much energy is required to remove logs from stumps to roadside using mechanized harvesting as is required using a semi-mechanized system. Some of their results are given in Table 4.4. It can be seen that the smaller the log diameter the greater the difference in energy required.

Table 4.4 Direct and indirect energy requirements for mechanized and semi-mechanized harvesting - stump to roadside (from Gasslander *et al.*, 1979)

	Semi-mechanized						Mechanized	
	Fell		Snig		Total		Total	
dbh	MJ/m^3	MJ/t*	MJ/m^3	MJ/t	MJ/m^3	MJ/t	MJ/m^3	MJ/t
15	30.1	26.4	28.6	25.0	58.7	51.4	230.1	201.5
20	17.7	15.5	28.2	24.7	45.9	40.2	162.5	142.3
30	10.0	9.0	27.9	25.1	37.9	34.1	122.7	110.3

* Assumes volume to green mass conversion using factors for radiata pine (Table 2.2)

Operator Transport and Haulage Distance

Modelled fuel use by mechanized and semi-mechanized logging systems, including fuel used for transporting operators to and from the forest, suggests that 86% more fuel is required by the mechanized system than for the semi-mechanized system when the forest is assumed to be 25km from workers' homes (McCormack & Wells, 1982). When the distance to the forest is assumed to be 50km, the difference falls to 38%. Fuel consumption for operator transport in semi-mechanized harvesting, allowing that operators travel to work independently in their own private vehicles, was calculated to be the equivalent of that required for chainsaw operation when travel distance is 25km, but twice that for chainsaw operation when travel distance is 50km. Operator transport is a much less important component of mechanized harvesting, there being fewer operators.

Obviously the requirement for fuel and repair energy for the hauling sub-operation increases in direct proportion to increasing log haul distance, progressively reducing the impact of mechanization in the felling and snigging phases of harvesting on the total energy required for the whole harvesting operation. Bent *et al.* (1978) found that, even though mechanization could lead to more than a doubling in the energy requirement for harvesting operations within the forest, i.e. felling and snigging, the fuel used to harvest wood by fully mechanized means and transport it 72km to pulpmills was never more than one-third above that required to supply wood harvested by a motor-manual system. This result is similar to that reported by McCormack and Wells (above).

Class of Log

Energy amounting to 84MJ/t is estimated to have been required to fell and snig sawlogs from mainly final crops in the Tumut plantation in 1977/78 (Table 4.1). For harvesting a 3:1 mixture of sawlogs and pulplogs energy amounting to 176MJ/t was required, and for pulplogs from first thinning the energy requirement for felling and snigging was 221MJ/t. So, as noted above in relation to the results of Gasslander *et al.*, considerably more energy per unit weight is required for small logs than for larger logs.

Trends in Harvesting

For the Tumut operations there was not a great deal of difference in the total energy expended in the three component sub-operations of harvesting, viz. felling, snigging and hauling, at least in the cases of pulpwood logging and logging for mixed sawlogs and pulpwood. Energy inputs to the stump to roadside operations, felling and snigging, become substantially greater as operations become more mechanized, but so too does energy expenditure on hauling as wood is transported further away, for instance to a pulpmill in Albury (distance 240km) and a medium density fibreboard plant in Wagga Wagga (130km). Improved utilization of smaller logs from second and third thinnings, and the changing age class distribution of the forest, will also lead to increased energy use per hectare At the time of the study, pulplogs came only from first thinning operations and the ratio of pulplogs to sawlogs was the inverse of that today, i.e. 2:1 cf 1:2 (Table 4.5).

Table 4.5 1977/78 cut (m^3) and anticipated annual cut (1981-1984), Tumut sub-district.

	77/78	1981	1982	1983	1984
Sawlog	59,809	100,400	119,400	121,900	121,900
Pulpwood	31,184	60,000	179,000	253,000	253,000
	90,993	160,400	296,400	374,900	374,900

The energy inputs to harvesting found in the Tumut study are considerably higher than those found by Gasslander *et al.* (1979), and by McCormack and Wells (1982). This is likely to be a reflection of the inefficiencies of energy use in actual year-round operations compared to modelled operations and energy use observed in the short term. If this is so, it indicates that there is room for energy savings by more efficient working methods under the stimulus of energy auditing.

Chapter Five

NET ENERGY YIELD FROM A PLANTATION

Calculation of Net Energy Yield and Energy Ratio

The gross energy required annually to grow and harvest each hectare of a first rotation radiata pine plantation in the Tumut sub-district has been estimated in Chapter 3. To arrive at the theoretical *net energy requirement* - defined as the gross energy requirement of a process less the enthalpy of combustion of the products where these are combustible - it is necessary to know the energy potentially available from the plantation. Normally, net energy requirement is positive but in the case of primary production where there is energy input from the sun via photosynthesis, it can be negative. Energy analysis, being concerned with depletion of globally-stored energy, does not take direct solar energy into account: it is considered a 'free' energy source. We shall see that producing, harvesting and delivering softwood from plantations to processing plants does indeed have a theoretical negative net energy requirement, i.e. the energy yield is greater than the energy input. *Net energy yield* - the gross energy yield (energy output) minus the gross energy requirement (energy input) - is therefore calculated instead of net energy requirement so that we are dealing with positive values. The *energy ratio* is calculated as the ratio of gross energy output to gross energy input.

- Chapter 5 -

The energy content of wood and bark of radiata pine has been equated with the energy released at the time of direct combustion (enthalpy) of air-dry material. In calculations of net energy yield, this is presumed to take place at the door of the wood processing plant. Calculations are done on an air-dry (15% moisture content) basis since woody material could eventually reach this stage naturally: to get wood into an oven-dry state would require input of energy and no allowance has been made for this. Similarly, no allowance is made here for conversion of roundwood to forms more suited for use as a fuel. The net energy yields calculated are thus theoretical maxima for each of the four utilization options examined. Conversion of wood to different forms of fuel, e.g. charcoal, wood gas and alcohol, all entail a loss of some energy compared to direct combustion due to inefficiencies of the conversion process. Such conversion will be discussed later.

Two of the four options which will be examined involve harvesting only softwood from the Tumut plantation, but two also involve harvesting eucalypt wood left on the plantation site after clearing native vegetation. Apart from the better utilization of wood, none of these options imply any major departure from plantation management as practised at the time of data collection.

'Windrowing' is now a standard procedure when clearing eucalypt forest for plantation establishment. This entails pushing up felled eucalypt trees into long parallel rows so that the ground between the windrows can be cultivated. Strictly, according to the guidelines for energy analysis laid down by the IFIAS (IFIAS, 1974), if this wood is burned, the enthalpy of combustion should be included as an energy input to growing pines. Two estimates of net energy yield and energy ratio have therefore been made for each utilization option, one including the energy released by burning windrows as an input and the other ignoring it. Enthalpy of combustion has been taken as 16.7 GJ/t(air-dry) for the wood of radiata pine (Fung *et al.*, 1968) and 17.5 GJ/t for the bark(based on the fact that Madgwick *et al.* (1977) found a difference of 0.8 GJ/t for wood and bark of radiata pine dried at 60°C), and 15.6 GJ/t for air-dry eucalypt wood (Fung *et al.*, 1978).

Option I - utilizing merchantable boles only

The 'merchantable' bole of a pine extends from the stump about 5 cm above ground to a small-end diameter of 10 cm. The yield of merchantable boles from Tumut plantations, divided into wood and bark, is shown in Table 2.2. The energy input to growing and harvesting these merchantable boles has already been calculated (Table 3.4). The net energy yield and energy ratio, assuming merchantable boles only are harvested, are calculated below.

Yield (tonnes air-dry per hectare per annum)

merchantable bole

wood 365.9t/40yr = 9.15 bark 46.3t/40yr = 1.16

Energy Output (GJ/ha.yr)

wood	9.15t x 16.7GJ/t	= 152.8
bark	1.16t x 17.5GJ/t	= 20.3
total		173.1

Energy Input (GJ/ha.yr)

merchantable bole (from chapter 3)		=	5.4
burning windrows 212t*/40yr x 15.6GJ/t		=	82.7
total (incl. windrows)			88.1

Net energy yield (GJ/ha.yr)

not incl. windrows	173.1 - 5.4	=	167.7
incl. windrows	173.1 - 88.1	=	85.0

Energy ratio

not incl. windrows	173.1/5.4	=	31.8:1
incl. windrows	173.1/88.1	=	2.0:1

* see Option III

Option II - utilizing total boles plus stumps

There is potentially more energy to be got from a plantation than from merchantable boles alone. Assuming it would not be practical to remove the small amount of non-pine material and small roots, and ecologically undesirable to deplete the site of nutrients by removing branches and foliage#, the stumps and non-merchantable boles are available as potential additional energy sources. Account must be taken of the additional energy required to harvest this material.

Taking the merchantable bole to be 95% of the total bole mass (Forrest & Ovington, 1970), and using the conversion factors in the notes to Table 2.2, there are an additional 19.3 tonnes of air-dry wood and 2.4 tonnes of air-dry bark (equivalent to 37 tonnes of green logs for the purpose of calculating additional harvesting energy involved) in non-merchantable boles which could be harvested from a hectare in a full rotation. This would give a total bole yield per year, including bark, of 9.15 + 1.16 + ((19.30 + 2.4)/40) = 10.85t(air-dry)/ha.

Madgwick *et al.* (1977) found that, while foliage was only 3% of the biomass of a 22 year old radiata pine plantation it contained 35% of the nitrogen and phosphorus bound up in the trees.

Forrest (1969) quotes from a number of studies to argue that about 16% of the total biomass in a radiata pine plantation comprises stumps and roots greater than 0.5 cm diameter. This means that the mass of stumps and roots is equal to about 19% of above-ground mass. Pine boles comprise about 85% of the total above-ground mass (Madgwick *et al.*, 1977) so the above-ground mass for the Tumut plantation can be taken as 10.85/0.85 = 12.76 t(air-dry)/ha.yr. The yield of stumps and roots is therefore 12.76 x 0.19 = 2.42 t(air-dry)/ha.yr (equivalent to 4.4 t/ha.yr green logs). Assuming the same proportion of bark to wood for roots as for boles, 2.15t of this is wood and 0.27t is bark.

The net energy yield and energy ratio, assuming total boles plus stumps are harvested, are calculated below.

Yield (tonnes air-dry per hectare per annum)

merchantable bole (as for Option I)				
wood		= 9.15	bark	= 1.16
non-merchantable bole				
wood	19.3t/40yr	= 0.48	bark 2.4t/40yr	= 0.06
stump				
wood		= 2.15	bark	= 0.27
total		11.78		1.49

Energy Output (GJ/ha.yr)

wood	11.78t x 16.7GJ/t	= 196.7
bark	1.49t x 17.5GJ/t	= 26.1
total		222.8

Energy Input (GJ/ha.yr)			
merchantable bole (as for Option I)		=	5.4
non-merch. bole*	37.0t/40yr x 0.534GJ/t	=	0.5
stump*	4.4t x 0.534GJ/t	=	2.3
total (not incl. windrows			8.2
burning windrows (as for Option I)		=	82.7
total (incl. windrows)			90.9
Net energy yield (GJ/ha.yr)			
not incl. windrows	222.8 - 8.2	=	214.6
incl. windrows	222.8 - 90.9	=	131.9
Energy ratio			
not incl. windrows	222.8/8.2	=	27.2:1
incl. windrows	222.8/90.9	=	2.4:1

* Assumes energy per tonne required to harvest non-merchantable boles and stumps to be 1.5 times that required for pulplogs (see Table 3.2), i.e. 1.5 x 0.356GJ/t = 0.534GJ/t

Option III - utilizing total boles plus stumps plus eucalypt wood remaining after burning windrows

Measurements made during a burning exercise in 1968 in a representative compartment in the Tumut sub-district (compartment 545) indicate that about 212 tonnes (air-dry)/ha of plant material, consisting of leaves, twigs and branches of felled eucalypts and other native species, might be consumed when windrows are burned (P. Cheney, pers. comm.). The measurements also indicate that about 309 tonnes of wood in a semi-green condition might remain after burning (equivalent to 222 tonnes air-dry if 60% m.c. assumed). The theoretical net energy yield and energy ratio for a first rotation, assuming this wood was harvested together with the boles plus stumps of radiata pine, are calculated below.

Yield (tonnes air-dry per hectare per annum)

total bole plus stump (as for Option II)

pinewood	= 11.78	bark	= 1.49

eucalypt wood remaining after burning windrows

euc. wood 222.0t/40yr = 5.55

Energy Output (GJ/ha.yr)

pinewood	11.78t x 16.7GJ/t	=	196.7
bark	1.49t x 17.5GJ/t	=	26.1
euc. wood	5.55t x 15.6GJ/t	=	86.6
total			309.4

Energy Input (GJ/ha.yr)

total bole + stump (as for Option II)		=	8.2
euc. wood*	222/40yr x 0.534GJ/t	=	3.0
total			11.2
burning windrows (as for Option I)		=	82.7
total (incl. windrows)			93.9

Net energy yield (GJ/ha.yr)

not incl. windrows	309.4 - 11.2	=	298.2
incl. windrows	309.4 - 93.9	=	215.5

Energy ratio

not incl. windrows	309.4/11.2	=	27.6:1
incl. windrows	309.4/93.9	=	3.3:1

* Assumes energy per tonne to harvest eucalypt wood is similar to that for non-merchantable pine boles and stumps (0.534GJ/t).

Option IV - utilizing total boles plus stumps plus all eucalypt wood greater than 7.6 cm mid-diameter

From data collected for the burning exercise mentioned before there are approximately 360 tonnes (air-dry) per hectare of eucalypt trunks and branches with a mid-diameter greater than 7.6 cm (3 inches) on the site before burning (equivalent to 626 tonnes (green) per hectare assuming 100% moisture content), and 74 tonnes (air-dry) per hectare of leaves, twigs and small branches. It might be feasible to harvest the material greater than 7.6 cm in diameter at the time of clearing, leaving the smaller material to be burned during site preparation. If this were done the net energy yield and energy ratio for the first rotation would be as calculated below.

Yield (tonnes air-dry per hectare per annum)

total bole plus stump (as for Option II)

wood	= 11.78		bark	= 1.49

eucalypt pieces larger than 7.6 cm in diameter

wood* 360t/40yr = 9.00

Energy Output (GJ/ha.yr)

pinewood	11.78t x 16.7GJ/t	= 196.7
bark	1.49t x 17.5GJ/t	= 26.1
euc. wood	9.00t x 15.6GJ/t	= 140.4
total		363.2

Energy Input (GJ/ha.yr)

total bole + stump (as for Option II)		= 8.2
euc. wood#	626t/40yr x 0.534GJ/t	= 8.4
total		16.6
burning windrows	74t/40yr x 15.6GJ/t	= 28.9
total (incl. windrows)		45.5

Net energy yield (GJ/ha.yr)		
not incl. windrows	363.2 - 16.6	= 346.6
incl. windrows	363.2 - 45.5	= 317.7
Energy ratio		
not incl. windrows	363.2/16.6	= 21.9:1
incl. windrows	363.2/45.5	= 8.0:1

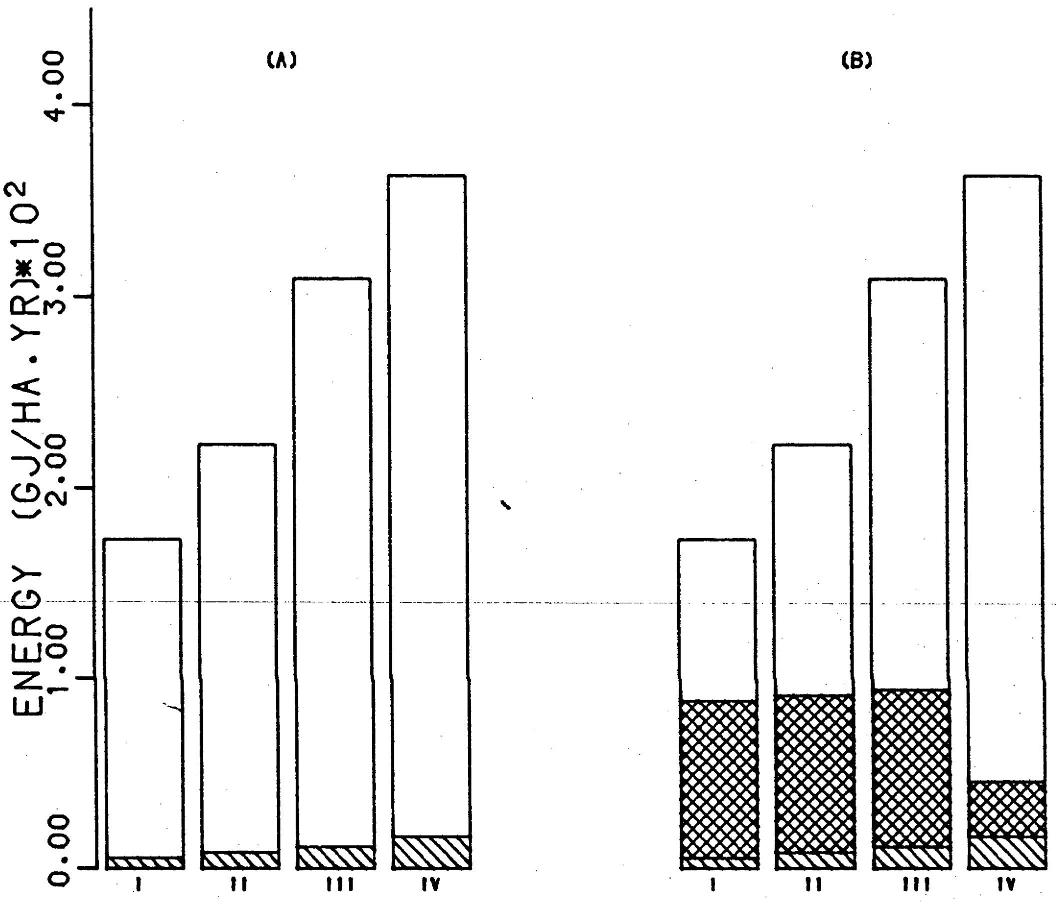
* Separate estimates have not been made for bark

\# Assumes energy per tonne to harvest eucalypt wood is similar to that for non-merchantable pine boles and stumps (0.534GJ/t).

Comparison of Results for Different Utilization Options

Table 5.1 lists values for net energy yields and energy ratios for utilization options I-IV and Figure 5.1 shows energy inputs when energy released by burning windrows is ignored (A), and when it is included as an input (B). Theoretically the greatest net energy yield for the first rotation would be achieved if all eucalypt pieces greater than 7.6 cm in diameter were harvested together with the boles and stumps of radiata pine (option IV). The assumption made in calculating the values shown in Table 5.1, that the energy input per tonne to harvest non-merchantable pine and eucalypt wood is one and a half (1.5) times that required for 'merchantable' pulpwood pine boles, might be in error but there are no data on which to base an estimate. The only practical way to harvest small diameter, crooked pieces might be to chip them on site, necessitating expenditure of at least an additional 180 GJ per tonne (NZERDC, 1979, Appendix B11). Even if the energy requirement were several times that assumed, option IV would still give the greatest net energy yield. Figure 5.1 (B) illustrates how the net

FIG. 5.1 ENERGY INPUT AND NET ENERGY YIELD FOR DIFFERENT UTILIZATION OPTIONS



UTILIZATION OPTIONS

I MERCHANTABLE BOLE ONLY

II TOTAL BOLE + STUMP

III TOTAL BOLE + STUMP + EUCALPT WOOD REMAINING AFTER BURNING WINDROWS

IV TOTAL BOLE + STUMP + EUCALYPT WOOD AND BARK FROM PIECES > 7.6 CM MID-DIAMETER

LEGEND

ENERGY INPUT NOT INCLUDING WINDROW ENERGY

WINDROW ENERGY

NET ENERGY YIELD

energy yield for option IV is boosted over that for option III through some of the eucalypt wood otherwise burned in windrows being counted as a potential source of energy. Option III, in which only the eucalypt wood remaining after burning windrows is counted as an additional energy source, has a higher net energy yield than option II (total boles plus stumps) which in turn has a higher net energy yield than option I (merchantable boles only). This would be so even if the rate of energy consumption for harvesting non-merchantable portions of the tree were several times that assumed.

Table 5.1 Net energy yield (N.E.Y.) (GJ/ha.yr) and energy ratio for harvesting options I-IV, (A) ignoring energy released by burning windrows, (B) including energy released by burning windrows as input.

	(A)		(B)	
Option	N.E.Y.	ER	N.E.Y.	ER
I	167.7	31.8:1	85.0	2.0:1
II	214.6	27.2:1	131.9	2.4:1
III	298.2	27.6:1	215.5	3.3:1
IV	346.6	21.9:1	317.7	8.0:1

The ranking of net energy yields for utilization options I-IV remains the same whether or not energy released by burning windrows is considered as an input, however the order of the energy ratios is reversed. This is because the energy released from burning windrows is many times the input of energy to harvesting radiata pine so that the effect of the increasing energy requirement for harvesting as we go from option I to option IV is masked. The energy ratio for each option is much higher when energy from burning windrows is ignored than when it is included as an input. Values range from 32:1 (option I) to 22.1 (option IV) in the former case compared with 2:1 to 8:1 respectively in the latter.

There is plainly a negative net energy requirement for the process of growing and harvesting a radiata pine plantation. Expressed positively, as an annual net energy yield, this varied between 85GJ/ha and 346.6GJ/ha under the conditions examined. The practice of windrowing and burning eucalypt forest before establishing pines clearly entails substantial losses, not only of a potential raw material for industries such as pulp and paper and fibreboard, assuming these were established within economic hauling distance of the resource, but also of energy. In some other parts of Australia, for example, in South Gippsland in Victoria, where wood from native species goes to the Maryvale pulp mill, this loss has been significantly reduced by utilizing at least some of this native hardwood.

Chapter Six

PROJECTING ENERGY REQUIREMENTS AND NET ENERGY YIELD

The energy inputs and potential outputs from a radiata pine plantation in the southern highlands of New South Wales have been identified and quantified in the foregoing chapter. Some of the factors influencing inputs to and outputs from plantations are discussed below before attempting an estimate of annual energy requirements and potential net energy yield for the whole softwood plantation estate in Australia.

Factors Influencing Energy Inputs

The results reported for the Tumut sub-district are for a first rotation plantation grown on rolling to fairly steep terrain which first had to be cleared of native vegetation. Second rotation plantations established on flat country having relatively sparse vegetation, such as in South Australia, should require less energy per unit area since relatively little energy is needed for site preparation and not as much for roading. On the other hand, energy requirements might be higher than for Tumut for some operations - plantation establishment for instance, if fertilizers and weedicides were applied routinely. At the time the data for the Tumut sub-district were collected, planting, tending and pruning were all done by hand. No fertilizers or weedicides were used and a semi-mechanized harvesting system was in use, i.e. chainsaws were used for felling, trimming and crosscutting, and skidders or forwarders were used to move logs to loading points. The distance over which logs had to be transported to wood processing plants was about 25 kilometres. The energy implications of some different management and harvesting strategies are discussed below.

Class of Land Planted

There has been a trend in recent years for a significant proportion of softwood planting to be located on ex-grazing land. In the Tumut sub-district in 1977/78, 72 ha out of 1327 ha were planted on already cleared or partly cleared grazing land. In 1980 however, 600 ha of 960 ha planted were on former grazing land. Practically all planting in South Australia and the Australian Capital Territory, for a number of years past, has been on land originally cleared for grazing. Some energy, in the form of energy sequestered in weedicides and consumed directly in applying them, generally has to be expended on these sites in order to minimize competition from grasses (see below), but the overall energy input is likely to be less than for clearing native forest.

A stage may be reached, as land available for planting becomes scarce, when consideration will have to be given to planting steeper slopes than have been planted hitherto. This possibility is already under consideration in the Tumut district (L. Mors, pers. comm.). Energy consumption for most operations might be expected to rise as a consequence, although possibly less energy would be required for harvesting if some form of cable logging were used. Alternatively, productivity might be boosted on more accessible land by the application of fertilizer. This, too, incurs additional expenditure of energy, but is capable of giving a very good return on investment (see below). Fertilizer is now added to most pine plantations in Australia.

Use of Chemicals

(i) weedicide

Weedicide is in common use to control grass competition when plantations are established on land previously used for grazing. It might also be used routinely in future on newly cleared and cultivated land. Weedicide was applied at two rates in trials in the Tumut sub-district during 1979 and 1980: 12 kg active ingredient (a.i.) per ha of sprayed area (the sprayed area was about one-third of the plantation area) to control pasture grasses, and 6-8 kg a.i./ha for control of lighter growth such as native snow grass. Spraying was at the rate of about 1.2 ha/hr from a 1000 litre tank drawn by a 4-wheel-drive rubber tyred tractor. One application of the weedicide at the lowest rate, assuming an embodied energy of 190 MJ/kg a.i. (value for atrazine from McIntosh, 1980), represents an energy investment of 1056 MJ/ha, comprising:

	MJ/ha
weedicide	380
fuel	399
repairs	188
steel	83
labour	6
	1056

Applying the weedicide twice per 40 year rotation would add 53 MJ of energy per hectare per annum (1056/40 x 2). For Tumut this represents a 17% increase in energy required for site preparation.

Weedicide may also be used to control eucalypt and wattle regrowth. At Bombala, in southern New South Wales, 2,4,5-T at 6 kg a.i. in 30 litres of diesel per hectare is routinely applied from the air using fixed wing aircraft. The energy input associated with such chemical tending is approximately 2000 MJ/ha per application (Dawson, 1978) and, on some sites, up to three applications per rotation may be necessary for effective control of unwanted woody regrowth. Energy consumption for this form of tending could thus be as high as 150 MJ/ha.yr over a 40 year rotation - more than ten times the energy consumed in tending by hand in the Tumut sub-district (13 MJ/ha.yr). D. Wheen (pers. comm.) has suggested that the new cultivation technique of blade ploughing described later, while itself consuming more energy than the old method of disc ploughing, might markedly reduce woody regrowth through more thorough destruction of plant roots, perhaps obviating the need for chemical spraying. This is one instance of many when energy used in one operation impinges on energy required in another.

(ii) fertilizer

It has been found beneficial to add fertilizers to first rotation radiata pine plantations in Australia and the practice is likely to be essential to maintain productivity in second and subsequent rotations (Crane & Raison, 1981). Over 90% of the exotic plantations in Australia are fertilized at, or soon after, planting (Crane, 1981).

- Chapter 6 -

Perhaps the most intensive use of fertilizers during the establishment phase is by the Woods and Forests Department on sandy soils in the south-east of South Australia which are otherwise marginal for planting radiata pine. A 'complete mineral' NPK (11:2:5) and trace element mix is applied in six applications in the first four years following planting (Woods, 1976). Three applications are by hand, two by tractor and one from the air. The energy cost of doing this is of the order of 29 GJ/ha, comprising fertilizer 28 GJ/ha and application 1 GJ/ha. Other levels and frequency of fertilizer application will have other, generally lower, energy inputs.

While it is recognized that early application gives best results (Waring, 1973), adding fertilizer to trees ten or more years old can also lead to improved growth. Crane (1981), conducting fertilizer trials in thinned radiata pine stands around 20 years of age in the Australian Capital Territory, found that volume production, measured four years after application of fertilizer, could be increased by an average of 37% relative to stands which were not fertilized. A single aerial application of fertilizer at the levels used in these trials (320 kg/ha of nitrogen as ammonium phosphate and urea, and 130 kg/ha of phosphorus as superphosphate) would require energy of the order of 6 GJ/ha. Five applications - one applied after each thinning in the course of a rotation - would consume 30 GJ/ha which is approximately equal to that used in the intensive early fertilization described above. On an annual basis (assuming a 40 year rotation) this is equivalent to 725-750 MJ/ha.yr, or as much energy as is required annually in the Tumut sub-district for all operations except roading and harvesting.

Table 6.1 Estimates of total direct energy input (excluding harvesting) and potential output during a rotation of 25 years for different fertilizer/weedicide treatments. Stemwood production projected from measurements at age 7 years using a growth model.

Source: Dargavel & Cromer (1979).

Treatment		Total input energy (GJ/ha)	Total output of stemwood energy (GJ/ha)	Output/input ratio
Without weed control				
1	0	27.9	1448	51:1
2	P_1	28.7	2463	85:1
3	P_2	29.8	2619	88:1
4	P_3	33.3	2828	85:1
5	N_1P_1	35.9	2487	69:1
6	N_2P_2	51.3	2770	54:1
7	N_3P_3	97.8	2812	29:1
8	$N_1P_1K_1$	36.1	2427	67:1
9	$N_2P_2K_2$	52.1	2384	46:1
10	$N_3P_3K_3$	100.2	2913	29:1
With weed control				
11	0	28.4	2622	92:1
12	P_1	29.2	3378	116:1
13	P_2	30.3	3948	130:1
14	P_3	33.8	3663	109:1
15	N_1P_1	36.4	3353	92:1
16	N_2P_2	51.8	3887	75:1
17	N_3P_3	98.4	3863	39:1
18	$N_1P_1K_1$	36.6	3451	94:1
19	$N_2P_2K_2$	52.6	3721	71:1
20	$N_3P_3K_3$	100.7	4011	40:1

Weedicide is commonly applied with fertilizers where grass, bracken or shrub competition is a problem (Woods, 1973; Eilert, 1979; Dargavel & Cromer, 1979). Dargavel & Cromer, in the only published study of energy requirement for radiata pine plantations in Australia, have calculated the total direct energy inputs and potential outputs (considering stemwood only) associated with growing a second rotation plantation on a poor site in Gippsland, Victoria, under various fertilizer/weedicide regimes. Their results, reproduced in Table 6.1, show there is potentially a huge marginal energy return from phosphorus fertilizer and an even greater return from weed control at both high and low fertility. Treatment P_2 with weed control - weedicide together with phosphorus, as double superphosphate, at a level of 67 kg of elemental phosphorus per hectare - gave the best energy return on the site under study (energy ratio 130:1). Dargavel & Cromer emphasize the importance of carefully choosing the right weedicide and fertilizer treatments for the site to make the most efficient use of money and energy. For example, heavy applications of nitrogen - an energy intensive fertilizer - are not warranted. Treatment P_2 with weed control required about 0.1 GJ/ha.yr more input than treatment 0 without weed control over a rotation of 25 years for a return of 100 GJ/ha.yr more output, whereas treatment $N_3P_3K_3$ (807 kg N, 202 kg P, 232 kg K) with weed control required thirty times as much additional energy (3 GJ/ha.yr) for a return only 3% greater than for P_2.

Without weed control or fertilizers the direct and indirect energy required for all operations, except harvesting, for a 40 year first rotation plantation in the Tumut sub-district was calculated to be 1117 MJ/ha.yr (see Table 3.4) and the energy output, counting total boles, 182.2 GJ/ha.yr. The energy output at the Gippsland site was only 57.9 GJ/ha.yr for a similar energy input (1116 MJ/ha.yr). The greater return to energy invested on the more fertile Tumut site is thus demonstrated.

Burning Logging Debris

Debris from clearing or logging operations is generally heaped into windrows and burned to improve access to plantations for men and machines and also to reduce the fire hazard. Pines planted on the site of burnt windrows grow faster than those planted between the windrows. This is probably due to nutrients, particularly nitrogen and phosphorus, being more available to the plants after baking and subsequent leaching of the soil (Pryor, 1963). However, the additional growth would not be commensurate, in energy terms, with the large amounts of energy released from the windrows upon burning (see chapter 5 and Figure 5.1(B)). In an analysis carried out strictly in accordance with international conventions, this energy should be counted amongst energy inputs to plantation establishment. The energy requirements for forestry operations such as planting, tending, pruning and harvesting are presumably somewhat lessened through better access after burning the previous logging debris but, again, the energy saved would not be commensurate with the energy released by burning windrows. There is generally a greater mass of logging debris left after clearing for a first rotation than before a second or subsequent rotation.

first rotation

On the site studied at Tumut the air-dry mass of eucalypt logging debris burned was presumed to be 212 t/ha (see Option III - chapter 5):

the energy released by burning this wood (3300 GJ/ha) is higher than would be released on most new plantation sites, some of which might have scarcely any previous vegetation to be burned. Adopting the convention that energy released by burning windrows be spread over one 40 year rotation only (as for roading and site preparation), the additional energy input attributable to site preparation may vary from 0 to 82 GJ/ha.yr. The effect on net energy yield and energy ratio of recovering some of this wood as an energy output has been shown in Table 5.1 and Figure 5.1(B).

second rotation

In South Australia, where a considerable area of second rotation has been established, it is the practice to burn first rotation logging slash. Pine debris left at the end of the first rotation is being burnt in windrows at Bombala in the southern highlands of New South Wales also, and the practice will probably be followed in the Tumut sub-district where planting of the second rotation has begun (see Appendix A.19). As argued above, the energy released by burning this logging debris can be regarded as an energy input to growing the next rotation of pines; moreoever, whilst there may be a short-term fertilizer effect on pines planted on burnt windrows, Flinn *et al.* (1979) conclude that burning logging debris at the end of the first rotation in south-western Victoria is actually detrimental to the total nutrient status of the relatively sandy soil there. The burning of 66.6 tonnes (o.d.) of the 79.5 tonnes of logging residue and litter per hectare estimated to have been on the site after clearfelling a radiata pine plantation 28 years old (logging debris 84% burnt), was accompanied by the loss of 72% (220 kg/ha) nitrogen, 27% (8kg/ha) phosphorus, 21% (21 kg/ha) potassium, 31% (123 kg/ha) calcium, 16% (13 kg/ha) magnesium, 40% (8 kg/ha) sulphur, 30% (6 kg/ha) iron and 34% (4 kg/ha) manganese. Replenishment of these nutrients would involve expenditure of at least 19.3 GJ/ha.[1] This is equivalent to 0.7 GJ/ha.yr over a 28 year rotation. If to this is added the energy released by the combustion of all organic matter on the site (1500 GJ/ha or 53.6 GJ/ha.yr over a 28 year rotation) then burning logging debris from the first rotation has actually cost 53.6 + 0.7 = 54.3 GJ/ha.yr. If logging debris is not burnt, some energy must still be expended in preparing the site for cultivating, e.g. by roller chopping, but this is not likely to require more energy than say blade ploughing which, from data in Table 6.2, works out at only 0.04 GJ/ha.yr for a 28 year rotation.

Mechanization

It has already been pointed out that increased mechanization in harvesting can lead to substantially greater energy requirements (see chapter 4). Mechanization is also proceeding in other plantation operations: the likely additional energy requirement of mechanized pruning for instance, is illustrated by the case of a machine under development by the CSIRO Division of Forest Research in 1979. Using stem-clasping knives, operated hydraulically from a 40 KW agricultural tractor, 90 Slash pine (*Pinus elliottii*) trees per hour could be pruned to a height of five metres. The life of the pruning machine, which weighed 4,500 kg, was expected to be about 7000 working hours. The

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[1] Energy in chemicals alone - values from Grant and Walters (1978) and Dawson (1978) - but does not include replacement of Fe and Mn (no figures available).

direct and indirect energy required to prune a hectare planted with 1320 trees with this machine, assuming it is operated six hours a day by two men who drive 45 km to and from work in a six-cylinder utility, comprises:

	MJ/ha
fuel	5670
repairs	1706
steel	957
labour	296
total	8629

Repair energy was calculated assuming repair cost to be twice that for the tractor alone. Pruning by this machine would be almost four times as energy intensive as conventional pruning by hand in Tumut (2240 MJ/ha - Table 3.3). A machine similar to this is already in service in Queensland, while hydraulic shears worked from a tractor have been tested successfully in Western Australia.

Changes to already mechanized operations can also lead to changes in energy consumption. In 1980 blade ploughing was substituted for disc ploughing in the Tumut sub-district. Considerably better ground penetration was thereby achieved, the soil being 'fluffed' instead of being turned over. Two tractor-implement combinations were used: a Symonds 397 cm 3-tyne blade plough pulled by a Fiat/Allis 14B tractor, and two single-tyne, three point linkage blade ploughs pulled by a Mercedes 1100 tractor. The fuel energy required for site preparation by this new method was calculated to be 1181 MJ/ha from performance data supplied by the Forestry Commission (see Table 6.2). By comparison, disc ploughing requires about 695 MJ/ha.

Table 6.2 Rates of working, diesel fuel consumption and energy required per hectare for blade ploughing with two tractor-implement combinations.

Area (ha)	Fiat (hrs)	Mercedes (hrs)	Fuel (litres)	MJ/ha
49	62	32	1624	1269
48	69		1363	1087
39	38	36	1200	1178
44	63	10	1369	1191
			average	1181

Transport Distance

The effect of increasing the transport distance of men and logs has been discussed in chapter 4. The increase in energy input is mainly in the harvesting operation where journeys to and from the forest have to be made daily, or several times a day in the case of log trucks, year-round. For the purpose of estimating energy inputs to the softwood plantation estate in Australia a round-trip travel distance of 100 km has been assumed.

Factors Affecting Energy Output

Some of the factors affecting energy input to plantations may also affect energy output through their influence on productivity. For example, the addition of weedicide and fertilizer, or a different cultivation technique, while adding to the energy requirement, leads to greater productivity and thus, potentially, to a greater net energy output. Chapter 5 has shown how utilization standards determine theoretical energy outputs. It has been assumed in the discussion below of the effect of inherent site fertility (often assessed in terms of site quality indices) that currently merchantable bolewood only is harvested. A number of plantation management practices which strongly influence wood production and thus energy output are also discussed.

Site Quality

The effect of site quality on wood and bark yield and on net energy yield and energy ratio, under two harvesting regimes, is shown in Table 6.3. In calculating net energy yields and energy ratios, inputs to all operations, other than harvesting, were assumed to remain constant at levels found for Tumut. Energy inputs to semi-mechanized harvesting were calculated assuming transport distances for logs and men to be the same as for Tumut (25 km) with the energy required to harvest by fully mechanized means assumed to be twice that required for semi-mechanized (motor-manual) harvesting. Logging debris burned in the course of site preparation was not counted as an energy input. The energy output was equated with the enthalpy of combustion of the wood and bark (air-dry basis) produced annually on merchantable boles. The greater productivity on more fertile sites results in greater net energy yield, that for site quality I being almost twice that for site quality V. Increasing mechanization in harvesting only marginally reduces net energy yield but markedly lowers the energy ratio.

Table 6.3 Net energy yield and energy ratio for sites of different fertility. A - semi-mechanized harvesting, B - fully mechanized harvesting.

SQ	Annual Increment/ha				Net Energy Yield (GJ/ha.yr)		Energy Ratio	
	m^3 u.b.	t green	tonnes air-dry					
			wood	bark	A	B	A	B
I	32.3	35.9	17.6	2.2	323.3	315.3	36.1:1	19.4:1
II	29.1	32.4	15.9	1.9	290.5	282.3	36.0:1	19.3:1
III	25.6	28.5	13.9	1.7	254.5	248.2	35.4:1	19.1:1
IV	21.9	24.3	11.9	1.5	218.5	213.1	35.6:1	18.9:1
V	17.9	19.9	9.7	1.2	173.1	173.1	33.3:1	18.5:1

Notes

Site quality (SQ) as per South Australian classification.

Annual volume increment on merchantable boles (based on 40 year rotation) from South Australian yield tables (Lewis *et al.*, 1976).

Conversion to green and air-dry mass using factors in Table 2.2 assuming green logs at 98% m.c.

u.b. = under bark

Plantation Management

Once the site for planting has been chosen, management options which influence yield of wood, hence net energy yield, include intensity of land preparation, selection of genetic stock for planting, plant spacing, use of chemicals (fertilizers and weedicides), pruning and thinning regimes and rotation length.

(i) land preparation

The more thorough the land preparation the better the establishment and early growth of a plantation. Where the original forest cover has been cleared for planting, the site is generally prepared by windrowing and burning the original vegetation and cultivating the ground between the windrows as in the Tumut sub-district. This leaves the soil in a relatively weed-free state, aerated and better able to take in water. On land previously used for grazing, it has been common in the past for only the planting lines to be cultivated, leading to slower growth and sometimes windthrow because roots tend to be aligned in one direction.

(ii) planting stock

Nursery stock for Australian plantations has, for many years, been grown from seed gathered from 'plus' trees, i.e. trees of exceptional vigour and form. Genotypes are now being further improved using seed from seed 'orchards', i.e. small, isolated plantations of trees of proven genetic stock propagated by cloning. Results from 10-12 year old trials show that 20% more wood volume can be produced using seed from these orchards compared with control seed (Eldridge, 1982).

(iii) spacing

Most plantations have been established at 2.4 m x 2.4 m tree spacing but wider spacing is favoured today because great difficulty has been experienced in marketing early thinnings. This has meant closely planted plantations have had to be non-commercially thinned to maintain high rates of growth on selected stems. Now the market for small-sized logs has improved with the advent of more pulp and chipboard plants, some of the wood which previously would have been thinned to waste may be merchantable but, because of the large volume of small-sized logs becoming available, some non-commercial thinning will probably still be necessary. Under the convention that only wood harvested and delivered to processing plants is counted towards energy output, 'thinned-to-waste' wood would be excluded. Ferguson & Shepherd (1979) discuss strategies for keeping non-commercial thinning to a minimum, including wider spacing (possibly 3.5 m x 3.5 m), thinning larger rather than smaller trees (thinning 'from above') and clearfelling in shorter rotations.

(iv) pruning and thinnings

The timing and severity of thinning and pruning in plantations depends upon the markets for which the wood is being grown. For instance, radiata pine planted in agro-forestry ventures might be tailored for the high value plywood market. Although there is no necessity for early thinning because of the wide initial spacing generally adopted in agro-forestry, pruning must be quite severe and frequent to keep bolewood as knot-free as possible. Total biomass yield is adversely affected by thinning and pruning since photosynthesizing tissue is removed. Broadly speaking, thinning in conventional plantations is carried out in order to provide the greatest yield of merchantable timber, with pruning of the best stems to enhance their value for sawlogs or plylogs. In this respect, management of the Tumut plantations is typical.

(v) fertilizers and weedicide

Use of fertilizers and weedicides has already been discussed. Benefits are such that the application of fertilizers at least is likely to become routine for plantations, especially to boost fertility in second rotations. The widespread use of weedicides on the other hand, at least when applied from the air, is not likely to meet with public acceptance because of the possibility of environmental damage even though this mode of application is currently quite widely used in agriculture.

(vi) short rotation plantations

Plantations grown for maximum biomass production, without regard to log size or wood quality, have been shown to have a potentially higher energy output than conventionally managed plantations. An untended radiata pine plantation grown on an 18 year rotation in New Zealand produced 192 tonnes (o.d.) per hectare of harvestable biomass (10.7 t/ha.yr) compared with 261 tonnes (8.7 t/ha.yr) produced by a plantation with the same number of trees (1500/ha) on a similar site but managed more conventionally on a 30 year rotation (NZERDC, 1979). The latter plantation was non-commercially thinned to 370 trees per hectare when dominant trees reached 11 metres high, thereby forfeiting some wood with potentially an energy value. Separate energy analyses for each of these plantations gave net energy yields of 194.3 GJ/ha.yr and 159.6 GJ/ha.yr respectively. All biomass was assumed to be harvested from the former forest but only stemwood from the latter.

Energy Requirement and Potential Net Energy Yield for the Australian Softwood Plantation Estate

The Softwood Plantation Estate

Details of the Australian softwood estate are available in a report by the Forest Resources Committee (AFC, 1981). Plantation areas in each state, in public and private ownership, classified by species, are shown at 31st March, 1979, as well as estimates of future availability of sawlogs and pulplogs, age class distribution of plantations, and proportions of second rotation planting in different regions. In 1980 the total coniferous plantation in Australia totalled 718,272 ha with an age class profile similar to that for the Tumut sub-district plantation (Fig. 2.2). The report forecasts that the availability of logs will be as shown in Table 6.4. The ratio of sawlogs to pulplogs increases until by 2010 it is almost 2:1.

Table 6.4 Future availability of logs (Australian Forestry Council, 1981)

	'000 tonnes green* logs'				
	1985	1990	2000	2010	2020
Sawlogs	3347	4516	8308	11281	11794
Pulplogs	4273	5255	5902	6215	6507

* conversion from m^3 using factors in Table 2.2.

Since publication of the AFC report about 23,000 ha of pine plantations in South Australia and 2,300 ha in Victoria have been burnt (1983) necessitating salvage operations which include storing large numbers of logs under water. Assuming 60 percent of wood is successfully salvaged there has been a loss of approximately 1,200,000 tonnes of sawlogs and a similar mass of pulplogs (calculated from figures in Keeves and Douglas, 1983). Inevitably this must lead to reduced availability of logs compared to forecasts by the Forest Resources Committee but by spreading the losses over a decade or so, while, at the same time, reducing clear-felling ages to supplement sawlog supply in the short term, the total log supply should not be radically affected. Any possible overestimate of energy requirement which use of AFC figures might involve, will be offset, at least partly, by the greater energy required for harvesting smaller sawlogs which must be utilized to ensure supply to South Australian and Victorian wood-based industries.

Energy Inputs to a Second Rotation

Unfortunately, figures for second rotation planting throughout Australia are not tabulated in the report referred to above, but from histograms in the report showing annual planting by region, it is estimated that there will be about 20,000 ha of plantation in the second rotation by 1985. In most regions, second rotation planting has been a small proportion (less than ten percent) of the annual planting but in the south-east of South Australia, one-third or more of the annual planting since 1970[1] has been of second rotation. Second and subsequent rotations will obviously assume greater and greater importance in the years ahead, as first rotations mature. Based on a knowledge of the present plantation age structure and an annual planting programme of 30,000 ha, approximately the following proportions

1 the proportion will be substantially increased as a result of the 1983 fires.

of plantings will be second rotation:

1985	1990	2000	2010	2020
12%	15%	30%	85%	95%

In Table 6.5 energy inputs found for a first rotation in the Tumut sub-district are adjusted so as to apply more closely to a second rotation. The harvesting energy figures in the second rotation column are not specific to second rotation but include increased energy required for more mechanized felling and snigging and a doubling in energy for hauling to allow for a 50 km log haul. It will be assumed that these new figures apply to the following proportions of logs harvested in future:

1985	1990	2000	2010	2020
10%	30%	50%	60%	60%

Current and Future Energy Requirement for the Whole Estate

The procedure for finding the annual energy requirement for the whole plantation estate in specified years is as follows:

(a) compute energy requirements for harvesting, assuming log availability as forecast in AFC (1981) and using harvesting energy figures from Table 6.5 as outlined above

(b) compute energy requirements for once-per-rotation operations (viz. roading, site preparation, nursery, and plantation establishment) assuming (i) annual planting of 30,000 ha, (ii) no energy input to new roading on second rotation sites

(c) compute energy requirements for operations which are repetitive

Table 6.5 Energy requirements per operation for a 40-year second rotation based on data in Table 3.4

Operation	Tumut MJ/ha.yr	Multiplier	Second Rotation MJ/ha.yr	Comment
ROAD	401	x 0.0	-	No new roading.
MAIN	162	x 1	162	
SITE	317	x 1	317	Savings through not having to clear native vegetation in second rotation offset by routine application of fertilizer and weedicide and more energy-intensive cultivation techniques.
NURS	12	x 1	12	
ESTB	16	x 1	16	Planting with machine likely to be approximately equivalent to hand planting.
TEND	13	x 2	26	Allows for chemical tending in some areas.
PRUN	112	x 2	224	Allows for machine pruning in some areas.
PROT	84	x 1.5	126	Allows for use of helicopters and other aircraft, occurrence of major fires, outbreaks of disease.
	1117		883	
HARV*				
Fell and Snig				
Pulplogs+	208	x 1.5	312	Allows for introduction of more mechanized logging systems and operator travel of 100 km per day.
Sawlogs#	118	x 1.2	142	
Haul				
Pulplogs+	170	x 2	340	Assumes haulage distance of 50 km.
Sawlogs#	128	x 2	256	
Fc	4	x 1	4	

* per tonne

\+ weighted average for contractors involved in mixed (3:1 sawlogs: pulplogs by green mass) harvesting and harvesting of pulplogs only from first thinnings.

\# weighted average for contractors involved in mixed sawlog and pulplog harvesting and harvesting of final crop.

during a rotation, viz. road maintenance, tending, pruning, protection. A normal forest must be assumed for the purpose of these calculations, i.e. energy figures in Table 6.5 are multiplied by the area of the whole plantation estate at dates specified.

Current and future energy requirements for the whole plantation estate are shown in Table 6.6.

Table 6.6 Predicted Total Energy Requirement for the National Softwood Plantation Estate (TJ)

Operation	1985	1990	2000	2010	2020
Road	423.5	409.0	336.8	72.2	24.1
Main	137.7	158.7	196.0	215.3	219.9
Site	38.0	38.0	38.0	38.0	38.0
Nurs	14.4	14.4	14.4	14.4	14.4
Estb	19.2	19.2	19.2	19.2	19.2
Tend	11.3	13.2	17.1	21.0	24.9
Prun	97.2	114.0	147.6	181.2	214.8
Prot	72.2	83.9	106.2	123.8	137.6
Fell	448.0	729.4	1237.7	1619.8	1694.5
Snig	643.3	893.1	1350.8	1685.7	1763.4
Haul	1634.8	2190.4	3322.4	4175.0	4367.1
Harv (FC)	61.0	78.2	113.7	140.0	146.4
TOTAL	3600.6	4741.6	6900.1	8305.7	8664.5

The energy requirement in the year 2000 (6.9 PJ) is almost double that required in 1985 (3.6 PJ). By 2020, when the plantation estate would be 1.4 million ha, 8.7 PJ will be required. The substantial saving of energy through not having to construct new roads in second rotation plantations is more than offset by the additional energy required in more mechanized harvesting.

Net Energy Yield from the Plantation Estate

The energy which would theoretically be released by combustion of merchantable boles harvested annually from the whole plantation estate in accordance with AFC (1981) estimates of log availability, is shown in Table 6.7 along with estimates of energy required for growing and extraction of the crop. The theoretical net energy yield rises from 58.2 PJ in 1985 to 147.3 PJ in 2020; if wood from non-merchantable boles and stumps were included the net energy yield might be 28% greater (see chapter 5), viz 74.5 PJ in 1985 rising to 188.5 PJ in 2020. These figures are theoretical maxima since no allowance has been made for processing of any kind other than logging. Energy ratios, i.e. energy output:energy input, lie between 17:1 and 18:1.

Table 6.7 Energy Balance for the National Softwood Plantation Estate (merchantable boles) (TJ)

Year	Output	Input	Net Yield	Ratio
1985	61792.37	3600.59	58191.78	17.2:1
1990	79684.62	4741.62	74943.00	16.8:1
2000	119373.32	6900.06	112473.25	17.3:1
2010	149085.71	8305.67	140780.04	17.9:1
2020	155933.10	8664.50	147268.61	18.0:1

The programme used to compute these values and those in Table 6.6 is included as Appendix A.18.

A wide variety of factors has been shown to influence both energy inputs and outputs: too many to take account of in detail when attempting a preliminary energy budget forecast for the whole estate. However the approach adopted is believed to have resulted in worthwhile, reasonably realistic estimates on which some conclusions and recommendations concerning future management of softwood plantations can be based.

Chapter Seven

AUSTRALIAN PLANTATIONS AND ENERGY: CONCLUSIONS

Dependence on Oil

Plantation-grown softwood now occupies an important place in the Australian economy. At one time practically all softwood had to be imported; now Australia is moving towards self-sufficiency in supply, with large wood-based industries employing some 70,000 persons (BAE, 1984, Table VI), erected on the base of home-grown softwood. Obviously, interruptions to the supply of this wood could have severe repercussions. This study has confirmed that plantations, like most commercial processes, are dependent on fossil fuels. The total energy requirements of 3.6PJ in 1985 and 4.7PJ in 1990 are around 0.1% of national demand expected for those years.

The striking feature of forecast energy use by plantations (Table 6.8) is the high rate ofincrease in demand for energy. Significantly, most of the additional energy will be required in the form of high grade liquid fuel to power harvesting equipment. While increases in total energy requirements will be at rates of 5.7% p.a. between 1885 and 1990, and 3.8% p.a. between 1990 and 2000 when total energy requirement will be 6.9PJ, energy requirements for the operations felling, snigging and hauling, taken together, will rise by 6.9% p.a. and 4.5% p.a. in the same periods. Energy consumptions for harvesting will continue to rise quite strongly (2.4% p.a.) in the first decade of the new century after which the total energy requirements for the softwood plantation estate are expected to level out at between 8.3PJ/yr and 8.6PJ/yr. By contrast, the growth in national total energy demand and in the demand for petroleum transport fuels is expected to be 2.5% p.a. and 1% p.a. respectively for the decade 1981-1991 (DRE, 1983).

It has been shown in chapter four (Table 4.1) that around three-quarters of the energy used in harvesting operations is in the form of petroleum-derived liquid fuels. Petroleum fuels comprise a high proportion of direct energy used in other operations (see Table 3.5), and some indirect energy inputs are oil-derived. In an exercise using a now out-of-date energy absorption matrix it was concluded (Wells, 1984) that 86% of the total energy requirement for the Tumut plantation was supplied by oil, 13% by coal and 1% by other sources (see Appendix A.20). Attempts to repeat this analysis using more up-to-date figures (James *et al.*, 1982b) have been thwarted by the aggregation of the 109 sectors of the economy into 49 super-sectors which has made energy co-efficients so unspecific as to be practically meaningless, and in any event, primary energy input co-efficients were not available. Although large scale substitution of gas for oil has taken place in many industries and in homes in the past decade, this has not occurred in plantation operations; indeed, an increasing proportion of the total energy used is consumed as liquid petroleum fuels in harvesting operations. Assuming (conservatively) that four-fifths of the energy requirements in 1985 are satisfied from oil as the primary source, 0.23% (2.9PJ) of Australia's total consumption of crude oil will be used for plantation forestry in that year, rising to 0.28% (3.8PJ) in 1990 with the same assumption. Figures for national crude oil consumption from DRE, 1983).

In company with most other countries in the world, Australia is trying to lessen its dependence on oil. The policy of parity pricing of Australia's own production of crude oil (amounting to about two-thirds of current demand) against prices paid for imported crude oil has been an important factor in slowing growth in national demand from 1.5% p.a. in the decade to 1980 to a forecast 0.5% p.a. over the decade 1981-1991 (DRE, 1983). It is likely that between 1990 and 2000, while oil consumption by plantation forestry is increasing at around 4% p.a., there will be continuing pressure to reduce dependence on petroleum products still further. There will undoubtedly be further steep price rises and perhaps even the introduction of quotas. Plantation forestry will therefore be pressed to either cut back on its energy use or substitute other energy forms for oil.

As long as there is continued increased mechanization of operations, particularly in harvesting, there seems little likelihood that large savings of energy can be achieved, though small savings might be made through a variety of ways such as car pooling, using vehicles and machines with better fuel economy, better matching of machines to jobs etc. Bent *et al.*, (1978) reporting a survey of member companies of the Canadian Pulp and Paper Association, Woodlands Section, conclude similarly: 'a sizable reduction in energy consumption is possible only through a host of small savings'. This suggests that logging companies in Canada are already locked into mechanizations, since, from their own observations and the finding of Gasslander *et al.* (1979), mechanization may, at one stroke, double the energy consumed per unit mass of logs felled and extracted. The growth of mechanization in harvesting in Australia needs to be closely monitored to see that mechanized techniques are justified as far as possible on energy grounds as well as in money terms.

The operation where the greatest amount of liquid petroleum fuel is used - road hauling - does not lend itself to energy conservation measures. Already trucks are loaded up to (and beyond!) axle loads permitted by main roads authorities. Reducing the haulage distance or implementing some form of back-loading (logging trucks travel one way empty) would be ways of realizing large savings of energy. The former could be brought about either by locating processing plants closer to the forests, or growing the forests in closer proximity to the plants. Locating wood processing plants closer to the forests generally means they are more remote from their other needed goods and services and from the markets for their products. Because of the energy costs of the infrastructure required and the social upheaval involved, it might be easier to bring 'Birnam wood to Dunsinane'.

Even if there were products to be carried towards the forest, back-loading of log trucks would not be practicable because of their peculiar design and the need for fast turn-around. Possibly the use of other transport methods would be less energy-intensive, at least for pulpwood. For example wood which had been chipped in the forest could be conveyed by belt. This has not been seriously investigated in Australia. If the pulpwood plant is at a great distance from the forest then a combination of belt and railway might be used.

If substantial savings cannot be effected in the petroleum fuel-dominated energy needs of plantation forestry, then a changeover to other sources of liquid fuel may be necessary.

- Chapter 7 -

> In Australia the tyranny of distance has been largely overcome and replaced by the tyranny of distillate, and it is almost with a sense of relief that we are at last being forced to conserve our liquid fuels, to use them more efficiently and to develop alternative and renewable sources of them.
>
> ... given the fact that Australia is poorly off for oil but richly endowed with coal, further rises in the price of oil or in the uncertainty of its supply will make it increasingly attractive for us to convert coal to oil.
>
> (L.T. Evans, 1980).

South Africa already produces much of its liquid fuel requirement from coal but Evans sounds this note of warning:

> Massive investment would be required ... [to convert coal to oil] ... on a significant scale, and having made that investment it would not be easy to dismantle our synfuel industry if we found, in twenty years' time, that the effects of rising CO_2 levels made this desirable. Atmospheric CO_2 is already increasing at the rate of one part per million per year, largely as a result of the combustion of fossil fuel, and the dependence on coal to oil conversion for our liquid fuel could increase the rate of CO_2 release. Just what the environmental impact of rising atmospheric CO_2 will be is difficult to predict, but it is clear that we shall be in for a hotter time. Thus, coal to oil conversion could be a Faustian bargain, exchanging present pleasures for future fires. Indeed, the effects on climate of rising CO_2 levels may constitute, on a world scale, one of the major constraints on the continued use of fossil, as against renewable fuels.

Production of liquid fuels from oil shale or coal might make a major contribution to meeting Australia's needs in the long term (from about 2000 - NEAC, 1980 - Table 11.1). In the meantime liquified petroleum gas (LPG) already provides a substitute for petrol, and other fuels, notably methanol, ethanol and compressed natural gas, are being investigated for this purpose. Some of these might eventually be used in passenger cars, utilities and other engines using petrol in plantations but a substitute for diesel is required if a big impact on plantation use of oil-based liquid fuel is to be made. Over 70% of the liquid fuel used in Tumut plantation was diesel needed for heavy plant such as bulldozers, graders, harvesting equipment and trucks (Table 3.6). Research to find suitable substitutes for diesel is lagging, though it is believed that vegetable oils from crops such as rapeseed, sunflower, and linseed might, one day, be used (Stewart *et al.*, 1981). Resins and essential oils which can be extracted from certain plants such as guayule (*Parthenium argentatum*), *Euphorbia lathyris* and certain *Eucalyptus* species have potential also, and commercial cropping of these 'hydrocarbon' plants in Australia is being investigation (Stewart *et al.*, 1982).

Plantations as an Energy Source

As we have seen, softwood grown in plantations requires input of fossil fuel energy but, because the plantations themselves are capable of high rates of growth and the wood produced can theoretically be used as a fuel, the energy input can be regarded as an investment to increase the conversion rate of solar energy to a form in which it can be more readily used by man. Table 6.9 shows that there can be a high return on that investment. In 1985, for an investment (input) of 3.6PJ in the national softwood estate there was a theoretical return (output) of 61.8PJ, i.e. a return of 17.2PJ for every 1PJ 'invested'. Though the energy ratio remains nearly constant the amount of energy theoretically produced by plantations in excess of energy input grows rapidly year by year. By 2020 the net energy yield is 147.3PJ. If wood produced on non-merchantable boles and stumps is included net energy yield could be 74.5PJ in 1985 rising to 188.5PJ in 2020.

Direct combustion of air-dry plantation produce 'at the mill door', while a useful concept to provide an estimate of theoretical maximum energy output potential (gross enthalpy of combustion), is obviously not a practical way of utilizing wood for energy. Moreover, wood from merchantable boles would not, in reality, be available as an energy source, except in an emergency. The major energy resource in plantations is in the non-merchantable boles and stumps - 12.7PJ in 1985 rising to 41.2PJ in 2020. In the past, mill residue - as much as 50% of the log input at many mills - might have made a significant contribution, but today wood conversion is carried out far more efficiently and most of the mill residue is either sold as chips for manufacture of particle board, or paper products, or used for purposes such as landscape gardening. One new use for residues which is expected to expand quite rapidly, is for medium density fibreboard. Some wood processors do supplement their own energy requirements with wood residues however. The Mt Gambier government sawmill in South Australia which, at one time, produced 21 MW from five turbines to supply most of the electricity needs of the town, now saws so efficiently that there is only sufficient residue (mainly sawdust) to raise steam for use in the mill itself. Mill residues thus provide an unspecified and an uncertain future energy resource.

With current combustion technology any cellulose material can be used relatively efficiently to provide heat energy say for raising steam. Conversion of wood to other, often more convenient forms of fuel, entails energy losses of the magnitude outlined in Table 7.1.

A number of plants have been built in the United States to generate electricity from wood (Anon, 1978; Anon, 1980) but this is one of the thermally least efficient ways of using wood (or any other primary source) for energy. Blankenhorn *et. al.* (1978) calculate that 71% of energy potentially available through direct combustion is lost in converting wood to electricity via steam turbines.

Table 7.1 Product Energy Efficiency for Different Energy Forms derived from Wood

	Efficiency %
Wood	100
Charcoal	45
Methane	51
Hydrogen	58
Ethanol	31
Methanol	51

Notes

Product energy efficiency is the ratio of the energy in the product over the energy in the feedstock (other direct and indirect energy consumption not taken into account). Figures are from NZERDC (1979) page 63, except for charcoal which is from Earl (1963).

Liquid fuels

There has been interest recently in Australia and New Zealand, in whether or not their already extensive softwood plantations can be used to provide substitutes for petroleum fuels. In New Zealand, a study by NZERDC (1979) has concluded that perhaps 30% of that country's liquid fuel requirements might be met in the late 1990s from wood surplus to the national demand (including maintaining exports at the average annual level 1976-80). The same study states that 16% of projected petrol and diesel fuel requirements in New Zealand could be replaced with methanol manufactured from sawn timber residues (mainly radiata pine) by the year 2000. While methanol production appears to be more economic than ethanol because of better conversion efficiency (Table 6.2), ethanol processing technology is further advanced. In 1981, an American firm entered into an agreement with the New Zealand

Forest Service to develop an 'ethanol from wood' plant; at about the same time it was announced that the New Zealand government had decided to go ahead with construction of the world's first natural gas to gasoline plant (Anon, 1981b; Anon, 1981c).

In Australia Stewart *et al.* (1979) have calculated that methanol can be produced from wood via gasification, in a plant producing 100,000 tonnes of methanol per year, with a conversion efficiency (energy in products/energy inputs to conversion process) of 35%. They calculate that methanol, with an energy equivalent of 55 PJ annually, could be manufactured from plantation sources if the projected plantation estate were doubled so that at least one million hectares were available solely for fuelwood. However, they remind us that it would be several decades before this rate of production could be reached. Theoretically, converting all wood from a plantation estate of 1.4 million hectares (projected size of estate in 2020) to methanol, in several large plants, could yield methanol with an energy content of 66 PJ (188.5 x 35/100). Using only non-merchantable boles and stumps, the yield would be 14.4 PJ annually (41.2 x 35/100), theoretically more than enough to supply the total annual energy requirements of the plantation estate (8.7 PJ/yr - Table 6.9).

Energy plantations grown to produce a maximum yield of organic matter are likely to produce a higher net energy yield than conventionally managed plantations initially, though whether this advantage could be maintained through a number of rotations has not been tested. Most of the nutrients taken up by trees are stored in the needles and small branches (Madgwick, 1978): these parts would probably be harvested with boles and stumps from energy plantations. It is estimated (NZERDC,

1979) that nutrient replacement could account for 13% of the total energy inputs to a radiata pine energy forest grown on an 18 year rotation in New Zealand, compared with 8% for a conventional 30 year rotation plantation. Nutrient replacement after each rotation would be essential in Australia with its generally infertile soils and is likely to be expensive in money as well as energy terms. A separate energy analysis would be required to find out what the net *sustainable* energy yield might be from energy plantations.

Australia, with its abundant resources of coal, oil shale, natural gas and uranium, is not likely to grow plantations solely for energy. The strategy most likely to be adopted in respect of using plantation wood for energy is one recommended by the New Zealand Research and Development Committee (NZERDC, 1979, page 32):

> Since energy from trees is not yet proven as the solution to New Zealand's liquid fuel supply problem it would appear prudent to retain flexibility in the meantime by intensively managing plantation forests. [i.e. for timber]
>
> ... Wood from these forests could be used for energy and could provide the basis for transition to energy farming ...

Wood for oil

While the uncommitted resource is not large enough to provide more than a small proportion of the country's requirements for liquid fuel, wood can nevertheless substitute for oil in other ways. The most straightforward way is when wood is burned as a boiler fuel where oil would otherwise be used. It has been estimated by the United States Department of Energy that wood presently provides that country with the equivalent of 140,000 barrels of oil per day, with the likelihood that this could double by the turn of the century (Anon, 1980). This is the most effective way of using wood for energy. An interesting possibility for partial substitution of petroleum fuels is that of one day using wood to fuel efficient stationary or mobile steam engines. According to Pritchard (1981), this is already practicable; however the economic viability of using this mode of traction, which would be particularly apt for forest harvesting, has not been investigated. The cost of these steam engines would be 'affordable' only if they were mass-produced.

Wood can also substitute indirectly for fossil fuels as a structural material. The energy sequestered in (sawn) wood is low compared with other building materials (Appendix A.17). Figure 7.1 from Kreijger (1976) shows that considerably more energy is sequestered in a steel beam (designed to support 400 kg/m in this example) than in either a concrete or a wooden one. The difference becomes greater as the span increases. This is one example of many where the use of wood leads to savings of fossil fuel. Energy embodied in wood in the round is even less than in sawn timber. For radiata pine the indirect energy sequestered in logs harvested from the Tumut sub-district can be obtained by calculating the inverse of the energy ratio. This is 0.031 joules per joule of energy which would be released upon combustion allowing that merchantable boles only are harvested.[1] Using an average density for sawlogs and pulplogs of 1.9 m^3/t (air-dry) (Table 2.1) and assuming enthalpy of combustion of wood as 16.7 GJ/t (air-dry)

1 If total boles plus stumps are harvested, embodied energy is 0.037 J/J.

the energy embodied in radiata pine logs is 272 MJ/m^3 (0.27 MJ/litre for comparison with figures in Appendix A.17). For logs harvested from the total estate when operations are more mechanized, indirect energy sequestered might rise to 0.058 J/J for merchantable boles. Under the assumptions above, embodied energy would then be 510 MJ/m^3 (0.51 MJ/litre). If energy released by burning eucalypt windrows in preparation for a first rotation is counted as an input to the plantation, energy sequestered in logs is 0.555 J/J when merchantable boles only are harvested and 0.417 J/J when total boles plus stumps are harvested.

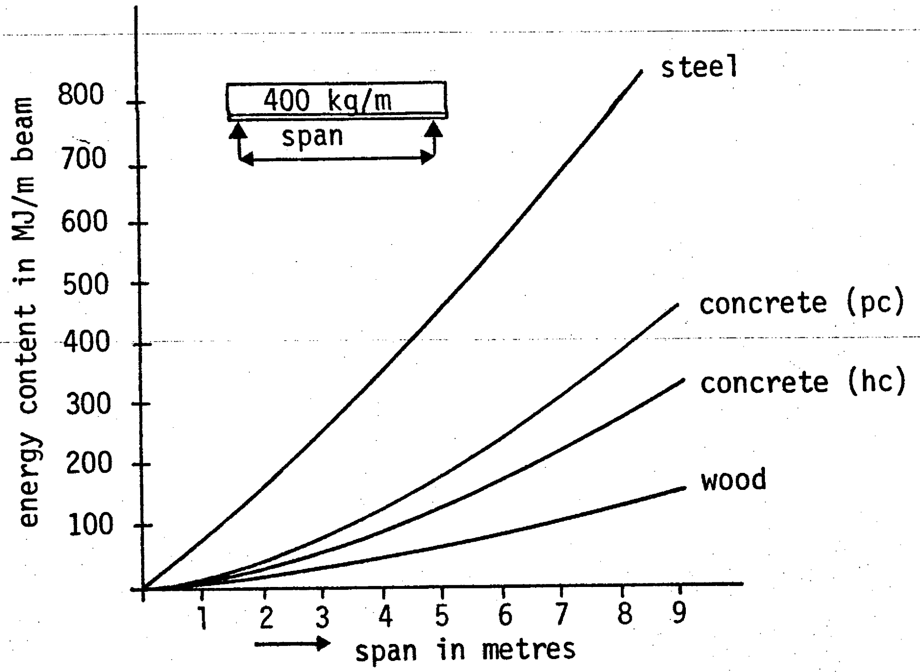

Figure 7.1. Energy embodied in wooden, reinforced concrete and steel beams.

pc = portland cement, hc = portland blast furnace cement

Source: Kreijger (1976)

The large increase in energy sequestered in plantation wood due to burning wood on the ground before planting highlights the large losses of energy entailed in this practice. Not only are there losses directly through combustion, but additional energy costs are incurred in the form of nutrient replacement (see Chapter 6). A comprehensive review of the practice on the grounds of fertilizer use as well as on energy grounds is overdue. At the same time the energy savings which might be achieved through the use of legume crops might be investigated. Lupins planted with marram grass to stabilize coastal sand dunes in New Zealand have been shown to fix at least 160 kg N/ha.yr and to provide much of the nitrogen taken up by radiata pine established subsequently (Gadgil, 1979). Crushing the lupins at the time of planting pines, and spraying lupin regrowth with an herbicide appears necessary to release trees from competition. At age 4, the above ground portions of the trees contain twice as much organic matter and nitrogen as the herbaceous plant tops when this is done, whereas, when the lupins are not suppressed, herbaceous plants contain more than twice as much dry matter and three times as much nitrogen as the young trees. Whether or not this practice results in overall conservation of energy needs to be verified. Trials using nitrogen-fixing plants (lupins and subterranean clover) have been conducted in conjunction with growing radiata pine in South Australia and in Western Australia.

Energy efficiency of land use

Fig. 7.2 shows the relative energy efficiency of a variety of forms of primary production, ranging from subsistence cropping through Canadian extensive forestry and western-world cropping to intensive primary production. The energy efficiency of Australian agriculture, overall, has been plotted from data of Gifford (1984), assuming the production requiring significant energy inputs takes place on a land area of 50 million ha. The energy efficiency of plantation forestry in Australia is indicated using data from Tumut plantations.

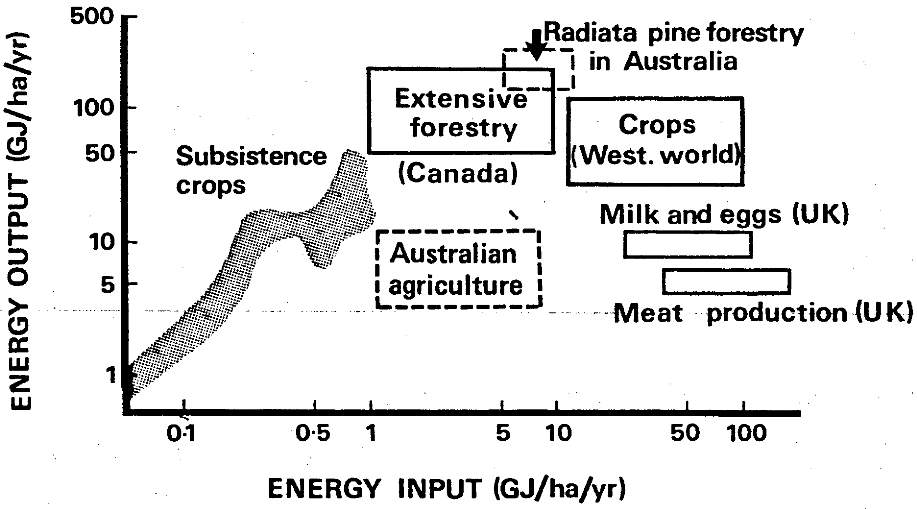

Fig. 7.2 — Energy inputs and outputs for different land uses (after Leach, 1976 and Overend, 1979)

It can be seen that the production of wood from plantations is a considerably more energy-efficient form of land use than western-world cropping, Australian agriculture, or intensive primary production. The efficiency of plantation forestry in Australia ranks with that of subsistence crops or extensive forestry in terms of energy ratio, but plantations are capable of considerably higher net energy yield. This is undoubtedly a point in its favour as a land use. In a world increasingly concerned with energy sources, particularly renewable ones, plantation forestry would attract much more support if its future role as an energy producer could be clarified. Energy analyses such as this one can help to do this.

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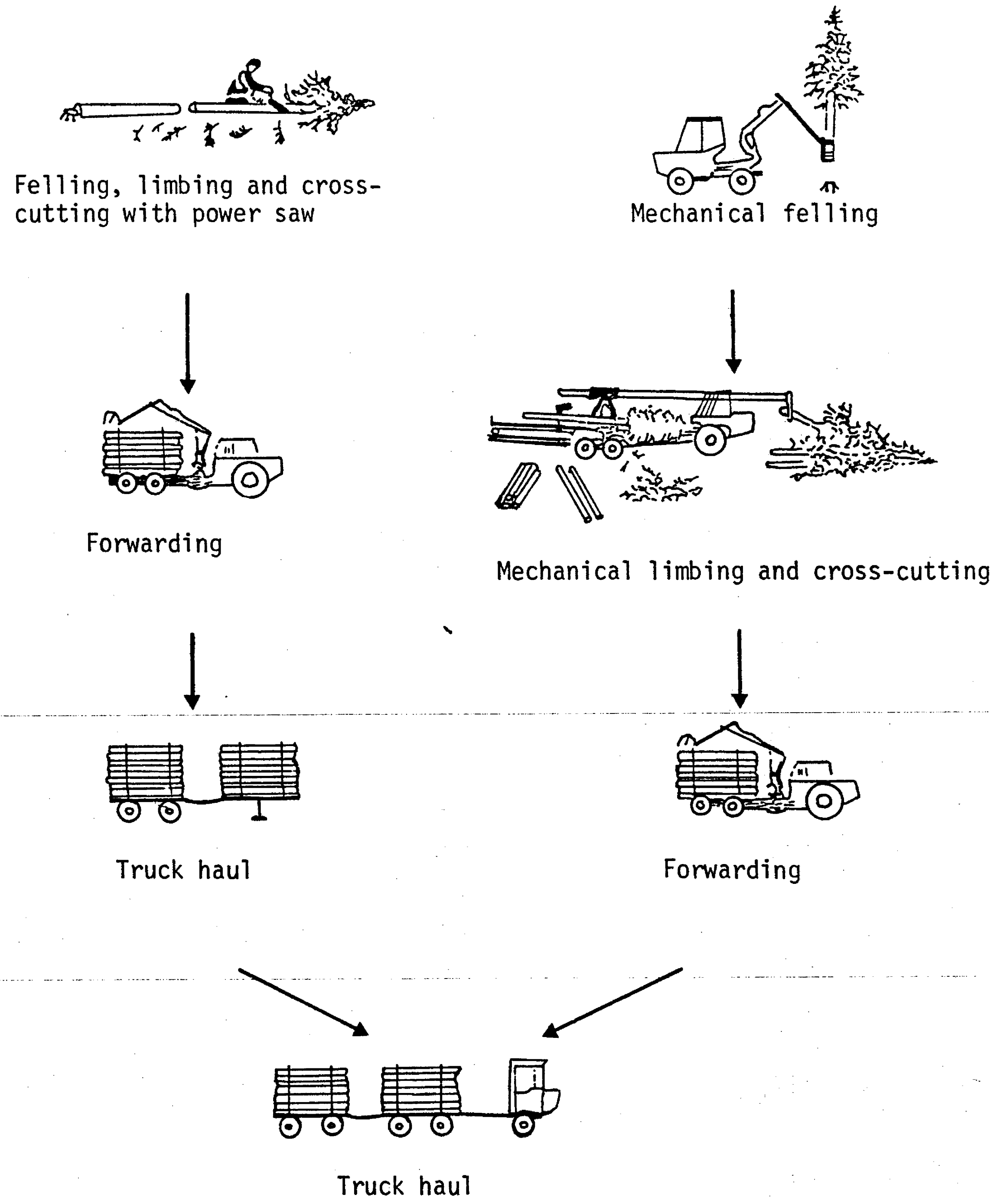
APPENDIX

- Appendix -



Appendix Figure A.1 Showing semi-mechanized and mechanized harvesting operations.

- Appendix -

Appendix Table A.1 Data and programme files used with UNIVAC computer and stored on magnetic tape.

	Input Category	Data	Programme
		(for computing energy inputs to forest operations other than harvesting)	
District	FUEL	ALLMACHDISTR FCONSUMERATE OPDISTR	ENERGY.FUELDISTR
Sub-dist	FUEL	NALLMACH2 WAGES FCONSUMERATE OPSUBD	ENERGY.FUELSUBD
District	REPAIRS	REPAIRATE	REPAIRS.MEANS
		ALLMECHDISTR	REPAIRS.ALLMECHDISTR
		REPDISTRSORT OPSORTDISTR	REPAIRS.OPSORTDISTR
Sub-dist	REPAIRS	ALLMECHSORT NREPAIRATE	REPAIRS.ALLMECH2
		ENEREPSORT OPSORT2	REPAIRS.OPSORT2
District	STEEL	ALLMECHDISTR PLANTARE	STEEL.ALLMECHD
		STEELDISTSOR OPSORTDISTR	STEEL.OPD
Sub-dist	STEEL	ALLMECHPLUS PLANTARE	STEEL.ALLMECH
		ENESTEELSORT OPSORT2	STEEL.OP
District	GOODS	GOODSDISTR PROCESSD	ENERGY.PROCESSD
		PARTDSORT INOUTPUTD	ENERGY.INOUTPUTD
		WHOLEDSORT OPSORTDISTR	ENERGY.OPD

- Appendix -

	Input Category	Data	Programme
Sub-dist	GOODS	GOODSORT PROCESS	ENERGY.PROCESS2
		PARTGOODSORT INOUTPUT3	ENERGY.INOUTPUT3
		WHOLESORT OPSORT2 (WHOLESORT = WHOLEGOODS - MACHMAINT3)	ENERGY.OP3
District	LABOUR	MANDISTR OPSORTDISTR	ENERGY.MANDISTR
Sub-dist	LABOUR	HOURSORT OPSORT2	ENERGY.MAN

(for computing energy inputs to the harvesting operation)

	Input Category	Data	Programme
	FUEL	NALLMACH2 WAGES FCONSUMERATE OPSUBD	ENERGY.FUELHARV
		FUELHARV	ENERGY.FUELHARV3
	REPAIRS	ENEREPHARV NREPAIRATE	REPAIRS.ENEREPHARV
		MACHMAINT3 (MACHMAINT3 = WHOLEGOODS - WHOLESORT)	REPAIRS.HARVEST
		MACHMAINT3	REPAIRS.HARVESTCON
	STEEL	ENESTEELHARV	STEEL.HARV
	LABOUR	MANHARV	ENERGY.MANHARV

(for computing net energy yield for the plantation estate)

ENERGY.PREDICT

APPENDIX TABLE A.2 EXAMPLE OF MACHINE USE DATA RECORD, TUMUT SUB-DISTRICT 1977/78. SEE APPENDIX TABLE A.5 FOR EXPLANATION OF PLANT CODE.

DATE	JOB			PLANT CODE					
1077	UTB2153B	P		VT2T4WD		HR	24	KM	370
0977	UTB2153B	P		VT2T4WD		HR	7	KM	120
0678	UTB2153E	P		VT2T4WD		HR	16	KM	352
0578	UTB2153E	P		VT2T4WD		HR	68	KM	1345
0378	UTB2153G	P		VT2T4WD		HR	54	KM	557
1177	UTB2153E	C	1040	P47A	02.00	HR	27		
1077	UTB2153A	C	654	P47A	02.00	HR	17		
1077	UTB2153B	P		V2T4WDCC		HR	10	KM	105
1077	UTB2153B	P		V2T4WDCC		HR	51	KM	379
0977	UTB2153B	P		V2T4WDCC		HR	12	KM	84
278	UTB2153G	C	192	COMPACVDR	41.02	HR	24		
578	UTB2153E	C	116	COMPACVDR	41.02	HR	14.5		
678	UTB2153E	C	48	COMPACVDR	41.02	HR	6		
1077	UTB2153A	P		V2T4WDCC		HR	34	KM	315
0977	UTB2153D	P		V2T4WDCC		HR	32	KM	293
0977	UTB2153B	P		V2T4WDCC		HR	24	KM	240
1077	UTB2153B	P		VT2T4WD		HR	68	KM	1057
0478	UTB2153E	P		VT2T4WD		HR	20	KM	193
1077	UTB2153B	C	280	TKCL4	41.02	HR	20		
1077	UTB2153B	C	420	TKCL4	41.02	HR	30		
1077	UTB2153D	C	504	TKCL4	41.02	HR	36		
1177	UTB2153J	P		VT2T4WD		HR	8	KM	60
777	UTB2153A	C	243	TKCL4	41.02	HR	18		
0278	UTB2153G	P		VT2T4WD		HR	63	KM	954
0478	UTB2153G	P		VT2T4WD		HR	64	KM	1249
0378	UTB2153G	P		VT2T4WD		HR	28	KM	411
378	UTB2153G	C	336	TKCL4	41.02	HR	24		
1177	UTB2153F	C	1260	TKCL4	41.02	HR	90		
0278	UTB2153G	P		VT2T4WD		HR	62	KM	1228
0678	UTB2153E	P		VT2T4WD		HR	20	KM	282
0478	UTB2153E	P		VT2T4WD		HR	24	KM	362
0877	UTB2153D	P		VT2T4WD		HR	25	KM	394
0578	UTB2153E	P		VT2T4WD		HR	45	KM	1145
1077	UTB2153A	P		VT2T4WD		HR	14	KM	501
0378	UTB2153G	P		VT2T4WD		HR	80	KM	859
0678	UTB2153E	P		VT2T4WD		HR	51	KM	1497
0278	UTB2153J	P		VT2T4WD		HR	18	KM	125
0578	UTB2153E	P		VT2T4WD		HR	61	KM	1434
1077	UTB2153A	P		VT7T		HR	52	KM	929
1177	UTB2153E	P		VT7T		HR	4	KM	65
0278	UTB2153G	P		VT7T		HR	2	KM	46
0178	UTB2153G	P		VT7T		HR	8	KM	115
0378	UTB2153G	P		VT7T		HR	13	KM	614
0977	UTB2153D	P		VT7T		HR	33	KM	396
0578	UTB2153E	P		VT7T		HR	2	KM	42
0278	UTB2153F	P		VT7T		HR	15	KM	123
0578	UTB2153E	P		VT7T		HR	3	KM	45
0378	UTB2153E	P		VT7T		HR	2	KM	51
0278	UTB2153G	P		VSW4WD		HR	1	KM	36
1077	UTB2153A	P		VSW4WD		HR	8	KM	151

APPENDIX TABLE A.3 RATE OF CONSUMPTION OF PETROLEUM PRODUCTS BY DIFFERENT PLANT TYPES. SEE APPENDIX TABLE A.5 FOR EXPLANATION OF PLANT CODE.

PLANT	PETROL (L/HR,KM)	DIESEL (L/HR,KM)	OIL (L/HR,KM)	GREASE (KG/HR,KM)
AEROXLT	20.00		.70	
COMPACVDR		5.46	.10	.01
COMPR75	4.00		.04	
FD105		11.00	.379	.04
FD145		12.00	.396	.04
FD160		14.00	.484	.04
FIRE ENG	1.14		.006	.0004
GRADRMH		17.20	.25	.01
GRADRMH4		14.16	.24	.01
GRADRMM		16.7	.27	.01
M30A	1.40		.03	
M33B	5.0		.06	
M34A	3.0		.03	
M35D	1.40		.16	
M35E	3.0		.03	
P47A		28.00	.45	.02
P54A		28.00	.50	.01
SK120		11.0	.553	.04
TK4WD110		12.5	.22	.01
TKCL4		8.70	.20	.02
TKCL5		19.70	.35	.02
TKCL6		37.42	.45	.02
TKCL7		44.37	.57	.02
TKFEL100		14.0	.41	.01
TKFEL130		12.90	.38	.01
TKFEL170		14.00	.68	.02
TKFEL60		6.87	.35	.01
TKWAG150		12.5	.22	.01
TKWAG40	11.8		.22	.01
TKWAG40D		7.9	.22	.01
TKWAG70	13.6		.32	.01
V2T4WDCC	.35		.003	.0002
VC2000	.11		.003	.0001
VC5000	.19		.003	.0001
VGP4WD	.28		.003	.0001
VGP4WDLT	.18		.003	.0001
VSSU15	.19		.003	.0001
VSW4WD	.25		.003	.0001
VT2T	.31		.003	.0002
VT3T	.35		.003	.0002
VT2T4WD	.35		.003	.0002
VT30C	.28		.003	.0001
VT5T		.35	.005	.0005
VT6T		.35	.008	.0005
VT7T		.40	.010	.0007
VT8T		.40	.010	.0009
VTFLOAT		.59	.017	.0015
VTLOG		.59	.017	.0015
VUV15+	.25		.003	.0001

APPPENDIX TABLE A.4 COST OF REPAIRS AND PARTS (INCLUDING TYRES) AND TYRES ONLY FOR VARIOUS PLANT. FIGURES ARE DOLLARS ($A 1978) PER HOUR OR PER KILOMETRE EXCEPT W = WEEKLY (40 HOURS). SEE APPENDIX TABLE A.5 FOR KEY TO PLANT CODE.

FC NO.	PLANT	REPAIRS (77/78)		REPAIRS (LIFE)	TYRES ONLY (77/78)	TYRES ONLY (LIFE)
0	AEROLT	.000		29.000	.000	.500
0	AEROXLT	.000		20.000	.000	.500
0	COMPACDR	8.170	W	9.110	.000	.000
0	COMPACVDR	.000	W	11.000	.000	.000
2549	COMPR75	4.170		5.790	.030	.030
8291	CRVNSLP	.000	W	.415	.000	.390
0	D15N	3.968	W	2.023	.000	.390
8131	D15N	11.300	W	2.190	.000	.390
8204	D15N	.000	W	1.370	.000	.390
8205	D15N	.000	W	1.300	.000	.390
8211	D15N	7.800	W	1.710	.000	.390
8284	D15N	.260	W	1.900	.000	.390
8302	D15N	4.710	W	2.380	.000	.390
8400	D15N	.000	W	3.190	.000	.390
0	D15P	2.297	W	2.133	.000	.390
8197	D15P	.000	W	.390	.000	.390
8223	D15P	8.930	W	3.680	.000	.390
8379	D15P	.000	W	2.940	.000	.390
0	FIRE ENG	1.337		1.135	.014	.007
5129	FIRE ENG	.713		.711	.032	.007
5141	FIRE ENG	.778		.472	.000	.005
5142	FIRE ENG	1.390		.624	.052	.008
5178	FIRE ENG	1.260		.624	.000	.007
5202	FIRE ENG	.802		.802	.000	.007
5205	FIRE ENG	3.080		3.580	.000	.007
6177	GRADRMH	8.980		5.690	2.090	.870
6152	GRADRMH4	16.200		5.240	1.990	.535
0	GRADRMM	3.200		3.200	.600	.600
0	M28B	.000		.045	.000	.000
0	M30A	.000		.059	.000	.000
9009	M30A	.000		.092	.000	.000
9030	M30A	.000		.045	.000	.000
9011	M32C	.000		.235	.000	.005
2636	M33B	15.700	W	2.940	.000	.000
0	M34A	4.683	W	4.195	.000	.000
4275	M34A	7.890	W	6.050	.000	.000
4293	M34A	8.310	W	2.580	.000	.000
4294	M34A	.000	W	1.180	.000	.000
4318	M34A	8.450	W	2.090	.000	.000
4391	M34A	3.450	W	7.780	.000	.000
4417	M34A	.000	W	5.480	.000	.000
0	M35D	1.472	W	2.340	.000	.000
7194	M35D	2.100	W	2.570	.000	.000
7234	M35D	.316	W	.684	.000	.000
7242	M35D	1.480	W	1.120	.000	.000
7302	M35D	1.950	W	1.960	.000	.000
7411	M35D	.000	W	6.620	.000	.000
7414	M35D	.000	W	2.370	.000	.000
7805	M35D	1.550	W	1.090	.000	.000
7938	M35D	4.370	W	2.310	.000	.000
0	M35E	1.175	W	.980	.000	.000

APPENDIX TABLE A.4 (CONT.)

5582	M35E	.000	W	.100	.000	.000
5610	M35E	2.350	W	1.860	.000	.000
0	P47A	.000		4.500	.000	.000
0	P54A	.000		3.100	.000	.000
0	SK120	.000		8.030	.000	1.880
0	TK4WD110	.000		7.000	.057	1.000
3362	TKCL4	1.160		1.160	.000	.000
0	TKCL5	4.040		6.630	.000	.000
0	TKCL6	24.840		13.100	.000	.000
3333	TKCL6	9.280		11.000	.000	.000
3334	TKCL6	40.400		15.200	.000	.000
3310	TKCL7	34.300		20.100	.000	.000
0	TKFEL100	2.900		2.900	.500	.500
0	TKFEL130	.000		7.900	.000	.400
0	TKFEL170	4.200		4.200	.700	.700
0	TKFEL60	14.650		7.330	.945	.680
3322	TKFEL60	13.500		6.830	.481	.291
3345	TKFEL60	15.800		7.830	1.410	1.070
0	TKWAG150	.000		8.000	.000	.900
0	TKWAG40	2.680		1.810	.000	.007
3287	TKWAG40	2.680		1.810	.000	.007
3337	TKWAG40	2.680		1.810	.000	.007
0	TKWAG40D	2.680		1.810	.000	.007
0	TKWAG60	.000		7.520	.000	.563
0	TKWAG70	.000		9.960	.000	.111
8224	TLF1000	18.700	W	7.170	.000	.200
8229	TLF250	.752	W	5.590	.000	.100
0	V2T4WDCC	.188		.151	.010	.005
1337	V2T4WDCC	.316		.201	.020	.006
0	VC2000	.000		.033	.000	.004
0	VC5000	.000		.034	.000	.004
0	VGP4WD	.067		.068	.004	.004
1031	VGP4WD	.067		.068	.004	.004
1694	VGP4WD	.067		.068	.004	.004
0	VGP4WDLT	.067		.068	.004	.004
0	VSSU15	.000		.034	.000	.004
0	VSW4WD	.264		.129	.016	.017
1045	VSW4WD	.047		.047	.000	.017
1399	VSW4WD	1.620		.125	.000	.007
1423	VSW4WD	.236		.236	.000	.017
1432	VSW4WD	.230		.157	.009	.007
1437	VSW4WD	.120		.118	.000	.001
1517	VSW4WD	.228		.119	.006	.006
1523	VSW4WD	.086		.094	.004	.003
1557	VSW4WD	.122		.139	.004	.003
1566	VSW4WD	.107		.090	.031	.015
1744	VSW4WD	.089		.069	.008	.005
1798	VSW4WD	.176		.117	.003	.001
1900	VSW4WD	.264		.264	.137	.137
1917	VSW4WD	.107		.107	.003	.003
1236	VT2T	.271		.092	.001	.003
0	VT2T4WD	.222		.180	.007	.006
1025	VT2T4WD	.232		.232	.000	.006

APPENDIX TABLE A.4 (CONT)

1413	VT2T4WD	.253	.230	.006	.009
1482	VT2T4WD	.089	.057	.003	.003
1533	VT2T4WD	.259	.185	.017	.006
1866	VT2T4WD	.117	.117	.004	.004
0	VT30C	.000	.051	.000	.003
0	VT3T	.125	.125	.005	.005
0	VT5T	.000	.150	.000	.014
0	VT6T	.000	.150	.000	.014
1631	VT7T	.104	.103	.041	.017
0	VT8T	.000	.183	.000	.023
0	VTFLOAT	.000	.183	.000	.023
0	VTLOG	.073	.073	.054	.054
0	VUV15+	.000	.051	.000	.003

APPENDIX TABLE A.5 MASS AND WORKING LIFE OF DIFFERENT TYPES OF MACHINERY AND PLANT CODE KEY+.

PLANT	MASS (KG)	LIFE (KM OR HR)	DESCRIPTION
AEROLT*	0	1	AIRCRAFT LIGHT
AEROXLT*	0	1	AIRCRAFT EXTRA LIGHT
COMPACDR	06100	030000	COMPACTOR/ROLLER DRAWN
COMPACVDR	12000	030000	COMPACTOR VIBRATING DRAWN
COMPR75	00956	005000	COMPRESSOR SMALL
CRVNSLP	01232	030000	CARAVAN
D15N	00330	020000	TRAILER 2 WHEEL 15 CWT
D15P	00813	020000	TRAILER 4 WHEEL 25 CWT
FD105	10550	020000	FORWARDER 105 HP
FD145	13000	020000	FORWARDER 145 HP
FD160	15200	020000	FORWARDER 160 HP
FIRE ENG	06280	070000	FIRETRUCK
GRADRMH	15200	030000	GRADER MED-HEAVY, CAT 130G
GRADRMH4	11202	030000	GRADER MEDIUM-HEAVY 4-W-D
GRADRMM	11000	030000	GRADER MEDIUM E.G. CAT 120G
M28B	00035	003000	ROTARY MOWER > 50 CM CUT
M30A	00075	010400	EARTH RAMMER
M32C	00457	015600	BITUMEN EMULSION SPREADER
M33B	00292	001000	ROTARY HOE 12 HP
M34A	00120	000500	PUMP 7 HP
M35D	00010	000800	CHAINSAW
M35E	00020	000500	ROCKDRILL E.G. TEX 20
P47A	04380	019000	DRILL RIG E.G. ATLAS COPCO
P54A	12425	012000	TRAXCAVATOR E.G. CAT 951C
SK120	10500	015000	SKIDDER 120 HP
TK4WD110	05000	005000	TRACTOR 4-W-D 110 HP
TKCL4	07280	010000	TRACTOR CLASS 4 E.G. CAT D3
TKCL5	14270	012000	TRACTOR CLASS 5 E.G. CAT D6
TKCL6	26633	012000	TRACTOR CLASS 6 E.G. CAT D7
TKCL7	34241	012000	TRACTOR CLASS 7 E.G. CAT D8
TKFEL100	10000	020000	FRONT-END LOADER 100 HP
TKFEL130	12930	020000	FRONT-END LOADER 130 HP
TKFEL170	16740	020000	FRONT-END LOADER 170 HP
TKFEL60	07195	020000	FRONT-END LOADER 60 HP
TKWAG150	06800	006000	TRACTOR WHEELED 150 HP
TKWAG40	02171	005000	TRACTOR WHEELED 40 HP PETROL
TKWAG40D	02171	005000	TRACTOR WHEELED 40 HP
TKWAG70	03266	005000	TRACTOR WHEELED 70 HP
TKWAGPRUN	04500	007000	PRUNING TRACTOR 40 HP
TLF1000	02254	042000	FUEL TRAILER 1000 GALLONS
TLF250	00650	042000	FUEL TRAILER 250 GALLONS
V2T4WDCC	03720	100000	TRUCK 4-W-D WITH CREW CAB
VC2000	00900	150000	PASSENGER VEHICLE TO 2 L
VC5000	01420	150000	PASSENGER VEHICLE TO 5 L
VGP4WD	01700	100000	VEHICLE 4-W-D , SWB
VGP4WDLT	00900	100000	VEHICLE LIGHT 4-W-D
VSSU15	01420	150000	VEHICLE UTILITY 15 CWT
VSW4WD	02000	200000	VEHICLE 4-W-D, LWB
VT2T	01900	150000	TRUCK 2 TON
VT2T4WD	04080	100000	TRUCK 2 TON 4-W-D

APPENDIX TABLE A.5 (CONT)

VT30C	01650	150000	TRUCK LIGHT 30CWT
VT3T	02000	170000	TRUCK 3 TON
VT5T	02542	200000	TRUCK 5 TON
VT6T	04100	200000	TRUCK 6 TON
VT7T	05340	250000	TRUCK 7 TON
VT8T	05500	250000	TRUCK 8 TON
VTFLOAT	13894	350000	FLOAT LOW LOADING
VTLOG	13894	350000	TRUCK LOGGING
VUV15+	01600	150000	VEHICLE UTILITY 20 CWT

* NEGLIGIBLE RATE OF CONSUMPTION OF COMPONENTS

+ CODES FOLLOW THOSE USED BY THE FORESTRY COMMISSION OF NSW AS FAR AS POSSIBLE (F.C. FORM 267) OTHERWISE THE COMMONWEALTH DEPT. HOUSING AND CONSTRUCTION CLASSIFICATION

APPENDIX TABLE A.6 EXAMPLE OF GOODS & SERVICES DATA RECORD
TUMUT SUB-DISTRICT 1977/78

	DATE	JOB		$	GOODS	ASIC	QUANTITY	
HOLST27	1277	UTB8108L	O	12	FREIGHT	51.01		
HOLST56	678	UTB9001	O	51	FREIGHT	51.01		
HOLST41	378	UTZ8108	O	28	FREIGHT	51.01		
UT69891	1077	UTB5406	M	265	FUNGICIDE	27.04	KG	80
UT69995	1277	UTB2153E	M	11	FUSE	27.07		
HOLST21	1177	UTB2153A	M	514	FUSE	27.07	M	3500
HOLST27	178	UTB2153E	M	216	FUSE	27.07	M	1500
UT69772	877	UTB3008	M	97	FUSE	27.07	M	500
UT69725	777	UTB1123	M	108	GALCANS	31.02	KG	9
HOLST50	578	UTB1123	M	79	GALVCAN	31.02	KG	6
UT69917	1177	UTB3008	M	10	GALVFTG	31.03		
UT73540	678	UTB2153G	M	30	GALVPIPE	29.01		
UT69899	1077	UTB3023B	M	206	GALVTANK	31.02	KG	300
UT69734	777	US 12	C	4910	GARAGE	41.02	NO	1
HOLST11	977	UTB5406	M	82	GASHEATER	33.03	NO	1
UT69772	877	UTB2051C	M	40	GELI	27.07	NO	120
HOLST49	478	UTB3023B	M	35	GERMICIDE	27.04	L	120
HOLST 5	877	UTB3023B	M	23	GLOBES	33.04	NO	100
UT70091	278	UTB3023B	M	23	GLOBES	33.04	NO	100
UW70187	877	UTB5406	M	10	GLOVES	24.02	PR	11
UT69817	977	UTB2051A	M	43	GRASSEED	01.06	KG	6.5
UT69848	1077	UTB2051A	M	282	GRASSEED	01.06	KG	400
UT73446	378	UTB4022	M	298	GRASSEED	01.06	KG	250
UT69847	977	UTB2153A	M	130	GRASSEED	01.06	KG	121
UT73499	578	UTB2153E	M	187	GRASSEED	01.06	KG	108
UT73475	478	UTB4022	M	74	GRASSEED	01.06	KG	36
UT69780	877	UTB3008	M	28	GRAVEL	14.00	M3	4.5
UT69975	1277	UTB2051D	M	83	GRAVEL	14.00	M3	13.5
UT69842	977	UTB3008	M	32	GRAVEL	14.00	M3	4.5
UT70022	178	UTB2051D	M	1728	GRAVEL	14.00	M3	8816
UT69962	1177	UTB3008	M	526	GRAVEL	14.00	M3	5255.2
UT70021	577	UTB2051D	M	162	GRAVEL	14.00	M3	5255
UT70021	1177	UTB2051D	M	162	GRAVEL	14.00	M3	5240
UT70022	178	UTB2151C	M	864	GRAVEL	14.00	M3	4408
UT69729	777	UTB2051A	M	191	GRAVEL	14.00	M3	22.5
UT69777	877	UTB1123	M	49	GRINDSTON	28.06	NO	6
UT69781	877	UTB1120B	M	44	GRINDSTON	28.06	NO	6
HOLST22	1177	UTB1123	M	20	HAMMER	31.03	NO	6
UW70205	977	UTB1123	M	26	HAMMERS	31.03	NO	6
HOLST15	1077	UTB2052A	M	34	HAMMERS	31.03	NO	6
PX72713	678	UTB1120B	M	80	HANDLES	25.03	NO	50
UW70252	1077	UTB1123	M	17	HANDTOOL	31.03		
UT73563	678	UTB3023B	M	10	HARDWARE	31.03		
UT70038	178	USZ 10E	M	20	HARDWARE	31.03		
UT73501	578	UTB2156A	M	32	HARDWARE	31.03		
HOLST42	478	UTB2153G	M	667	HEADWALL	28.05	NO	19
US68835	278	UTB3421E	M	160	HEATER	33.03	NO	1
UT69843	977	UTZ8037	M	32	HELMET	34.03	NO	1
05	7879	9021 T2	M	7	HELMET	34.03	NO	2
03	7778	UTB9010 T1	M	29	HELMET	34.03	NO	8
05	7879	9010 T2	M	18	HELMET	34.03	NO	5
05	7879	9021 CF	M	7	HELMETS	34.03	NO	2

APPENDIX TABLE A.7 EXAMPLE OF HUMAN LABOUR DATA RECORD
TUMUT SUB-DISTRICT 1977/78

	DATE	JOB		$				
UT73564	678	UTB9001H	W	165	MAN	77	HR	24
UT69767	877	UTB9001	W	36	MAN	85	HR	6
UT73479	478	UTB9001A	W	125	MAN	75	HR	21
UT73480	578	UTB9001	W	358	MAN	75	HR	58
UT69801	877	UTB9001	W	64	MAN	84	HR	11
UT69856	1077	UTB9001	W	48	MAN	83	HR	8
UT69884	1077	UTB9001	W	487	MAN	82	HR	82
UT69951	1277	UTB9001	W	72	MAN	83	HR	12
UT69938	1177	UTB9001H	W	97	MAN	82	HR	16
UT69938	1177	UTB9001	W	531	MAN	82	HR	88
UT69951	1277	UTB9001H	W	72	MAN	83	HR	12
UT69905	1177	UTB9001H	W	182	MAN	82	HR	30
UT69905	1177	UTB9001	W	681	MAN	82	HR	112
UT70059	278	UTB9001H	W	147	MAN	85	HR	24
UT70059	278	UTB9001	W	122	MAN	85	HR	20
UT70037	178	UTB9001H	W	97	MAN	83	HR	16
UT70037	178	UTB9001	W	560	MAN	83	HR	92
UT70018	178	UTB9001	W	637	MAN	85	HR	100
UT69981	1277	UTB9001H	W	102	MAN	84	HR	16
UT69981	1277	UTB9001	W	650	MAN	84	HR	102
UT69981	1277	UTB9004A	W	38	MAN	84	HR	6
UT70018	178	UTB9004H	W	268	MAN	85	HR	42
UT70037	178	UTB9004A	W	183	MAN	83	HR	30
UT70037	178	UTB9004H	W	97	MAN	83	HR	16
UT70037	178	UTB9004B	W	232	MAN	83	HR	38
UT70059	278	UTB9004B	W	428	MAN	85	HR	70
UT70059	278	UTB9004A	W	159	MAN	85	HR	26
UT70059	278	UTB9004H	W	263	MAN	85	HR	43
UT69905	1177	UTB9004A	W	213	MAN	82	HR	35
UT69905	1177	UTB9004H	W	170	MAN	82	HR	28
UT69905	1177	UTB9004B	W	347	MAN	82	HR	57
UT69938	1177	UTB9004H	W	157	MAN	82	HR	26
UT69938	1177	UTB9004B	W	459	MAN	82	HR	76
UT69938	1177	UTB9004A	W	85	MAN	82	HR	14
UT69951	1277	UTB9004H	W	216	MAN	83	HR	36
UT69884	1077	UTB9004A	W	71	MAN	82	HR	12
UT69884	1077	UTB9004H	W	142	MAN	82	HR	24
UT69884	1077	UTB9004B	W	214	MAN	82	HR	36
UT69856	1077	UTB9004A	W	66	MAN	83	HR	11
UT69856	1077	UTB9004H	W	95	MAN	83	HR	16
UT69856	1077	UTB9004B	W	143	MAN	83	HR	24
UT69951	1277	UTB9004A	W	132	MAN	83	HR	22
UT73480	578	UTB9004H	W	37	MAN	75	HR	6
UT73480	578	UTB9004B	W	542	MAN	75	HR	88
UT69951	1277	UTB9004B	W	300	MAN	83	HR	50
UT69801	877	UTB9004H	W	199	MAN	84	HR	34
UT69801	877	UTB9004	W	281	MAN	84	HR	48
UT73564	678	UTB9004A	W	89	MAN	77	HR	13
UT73564	678	UTB9004B	W	688	MAN	77	HR	100
UT69767	877	UTB9004	W	284	MAN	85	HR	48

Appendix Table A.8 Oil-derived fuels & lubricants used in the Tumut sub-district 1977/78, showing direct plus indirect energy equivalent.

	Litres				Gigajoules				
	PETROL	DIESEL	OIL	GREASE (kg)	PETROL	DIESEL	OIL	GREASE	TOTAL
ROAD	37149	142153	3083	143	1444	6098	145	7	7693
MAIN	10214	33329	866	42	397	1429	40	2	1869
SITE	24400	105718	2791	140	948	4534	131	6	5621
NURS	16495	117	158	6	641	5	7	-	653
ESTB	14158	0	81	3	550	0	3	-	554
TEND	13475	0	73	2	523	0	3	-	527
PRUN	57921	0	234	7	2251	0	11	-	2262
PROT	20760	3007	250	10	807	129	12	-	948
HARV	168524	322254	17921	970	6549	13823	843	47	21263

Appendix Table A.9 Direct plus indirect energy (GJ) consumed in repairs to machines in the Tumut sub-district in 1977/78. Figures in brackets are percentages.

	Tyres	Parts and Labour	Total
ROAD	126.3	2835.7	2962.0
MAIN	99.1	603.6	702.7
SITE	72.6	1569.6	1642.2
NURS	.5	55.3	55.8
ESTB	4.7	103.8	108.5
TEND	10.6	64.5	75.1
PRUN	25.9	247.7	273.6
PROT	13.9	327.8	341.7
HARV	1437.3	2478.8	3916.1
TOTAL	1790.9 (18)	8286.8 (82)	10077.7 (100)

Appendix Table A.10 The energy sequestered in various goods as found by process analysis.

Product	Energy Sequestered (GJ/t*)	Source
Aluminium	327	Gifford (1975)
Aluminium (extruded)	145	Dawson (1978)
Cardboard	41	Gifford (1975)
Cardboard	52	Berry *et al.* (1975)
Fertilizer		
compound	23	Gifford (1975)
ammonium nitrate	24	Dawson (1978)
ammonium nitrate	25	Nairn (1979)
superphosphate	2.1	Gifford (1975)
superphosphate	1.8	Dawson (1978)
superphosphate	1.5	Kirkam & Mathews (no date)
superphosphate	1.9	Dornom & Tribe (1976)
superphosphate	2.8	Handreck & Martin (1976)
Fungicide (DDT)	101	Gifford (1975)
Fungicide	135	Dawson (1978)
Fungicide ('Maneb')	99	McIntosh (1979)
Galvanised Iron	34.5	Dawson (1978)
Grass Seed	4	Croke (1979)
Herbicide	94	Gifford (1975)
Herbicide	130	Dawson (1978)
Herbicide	101	Handreck & Martin (1976)
Herbicide (2,4-D)	85	McIntosh (1979)
Insulation (fibreglass)	$30/m^2$	Kirkam & Mathews (no date)
Paper	39	Gifford (1975)
Paper	32.7	NZERDC (1976)
Posts (treated wood)	0.009ea	Dawson (1978)
Pipes		Dawson (1978)
concrete	4	Dawson (1978)
plastic	10.9	Handreck & Martin (1976)
Polythene (UK)	58	Berry *et al.* (1975)
Polythene (USA)	116	Berry *et al.* (1975)
Timber (sawn, treated)	$3.3/m^3$	NZERDC (1976)

* Except where otherwise indicated.

Appendix Table A.11 Oil derivatives consumed per tonne of green logs harvested, according to class of log.

	Petrol	Diesel	Oil	Grease	Total
Litres					
pulplogs	2.9	3.3	0.2		
mixed[a]	1.3	3.5	0.2		
sawlogs	0.7	2.6	0.1		
Megajoules					
pulplogs	115	143	1	1	269
mixed[a]	52	150	8	1	211
sawlogs	26	113	5	-	144

a Ratio sawlogs:pulplogs = 2.8:1

Appendix Table A.12 Area planted with Pinus species, 1974-78

		ha
	1974	34,344
	1975	35,818
	1976	30,969
	1977	36,630
	1978	34,645
Total to 1978		621,571

Source: Australia, Department of Primary Industry, Forest Resources, 1974, 1975, 1976, 1977, 1978.

Note

Most of the area planted annually is radiata pine, e.g. in 1978 *P. radiata* 78%, *P. elliottii* 15%, *P. caribaea* 5%, *P. pinaster* 2%.

- Appendix -

Appendix Table A.13. Percentage energy requirements for various plantation operations by input categories, Tumut sub-district.

Operations	FUEL	REPAIRS	GOODS	STEEL	LABOUR
ROAD	50.4	19.5	21.7	7.0	1.5
MAIN	57.4	21.6	12.3	6.2	2.5
SITE	67.2	19.6	2.8	10.1	.3
NURS	45.5	.0	45.5	.0	9.1
ESTB	68.8	12.5	.0	6.3	12.5
TEND	69.2	7.7	7.7	.0	15.4
PRUN	66.7	8.1	7.2	1.8	16.2
PROT	53.3	16.3	20.7	6.5	3.3
HARV	76.1	12.9	.4	8.5	2.1

Appendix Table A.14 Percentage energy requirements for various plantation operations by input categories, total Pinus estate.

Operations	FUEL	REPAIRS	GOODS	STEEL	LABOUR
ROAD	50.4	19.5	21.7	7.0	1.5
MAIN	57.4	21.6	12.3	6.2	2.5
SITE	65.0	16.0	8.0	8.5	2.5
NURS	45.5	.0	45.5	.0	9.1
ESTB	72.2	13.3	.0	6.6	8.0
TEND	73.1	8.1	8.8	.0	10.0
PRUN	71.3	8.6	7.2	1.9	11.0
PROT	53.3	16.3	20.7	6.5	3.3
HARV	77.2	12.9	.4	8.5	1.0

Appendix Table A.15 Energy requirements in MJ/ha.yr by input categories, total pinus estate.

Operations	FUEL	REPAIRS	GOODS	STEEL	LABOUR	TOTAL
ROAD	50.4	19.5	21.7	7.0	1.5	100
MAIN	93.0	35.0	20.0	10.0	4.0	162
SITE	206.0	50.7	25.4	26.9	7.9	317
NURS	5.0	.0	5.0	.0	1.0	11
ESTB	46.3	8.5	.0	4.2	5.1	64
TEND	19.0	2.1	2.3	.0	2.6	26
PRUN	159.7	19.3	16.1	4.3	24.6	224
PROT	73.5	22.5	28.5	9.0	4.5	138
HARV	8329.1	1391.8	43.2	917.0	107.9	10789
						11831

Appendix Table A.16 Possible future fuel systems for Australia.

Source: NEAC (1978)

Period	Electricity	Transport	Low grade heat
1970-1980 Fossil Fuel Economy	Coal Hydroelectric (10%) Natural Gas	Oil	Coal Petroleum Natural Gas
1980-2000 Transition Period	Coal Natural Gas Hydro (5%)	Oil Synthetic from Coal Methanol, Ethanol Coal? Electric Transport	Coal Natural Gas Solar
2000-On Electrochemical Hydrogen Economy	Coal Uranium Solar? Fusion?	Oil and Hydro-carbons, Methanol, Ethanol, Hydrogen? Batteries	Solar Coal

Note:

Contributions of less than 5 per cent to a particular energy source have been ignored (e.g. the hydroelectric potential in Australia is such that it would not be expected to contribute 5 per cent to electricity production in 2000). A question mark is given to areas where research is necessary to show technical feasibility.

Appendix Table A.17 Energy embodied in different building materials. Source: Kreijger (1976)

Materials	Energy content MJ/kg	MJ/l	Materials	Energy content MJ/kg	MJ/l
sand, gravel	0.1	0.16	ready mixed concrete	0.8	1.9
light weight aggregates	4.0	2.5	reinforced concrete*)	2.5	6.0
lime	6.3	8.2	prefab concrete elements*)	2.0	4.7
portland cement	6.4	8.0			
portland blast furnace cement	3.0	3.8	steamed prefab concrete elements	2.3	5.5
gypsum	3.6	2.9			
water	0.004		light weight concrete	2.3	4.15
			light weight reinforced concrete*)	3.8	7.2
baked clay bricks	4.3	7.7	steel	30	236
sand lime bricks	0.84	1.5	reinforcement	23	180
clay brick masonry	6.0	11.0	prestressed steel	28	220
sand lime brick masonry	2.7	4.9	aluminium	120	325
glass	21	56	copper	30	270
rockwool	14	2.2	zinc	50.5	360
asbestcement	5.1	9.0			
coal	29.3		wood(sawn)	4	2.4
oil	43		plastic	40	40
natural gas		35	bitumina	20	20

*) inclusive 100 kg reinforcement per m^3 concrete

Appendix A. 18 Computer program to forecast energy inputs and outputs, national softwood plantation estate

```
KF#652*ENERGY(23).PREDICT/DATA(10)
        'OPCODES'
                'ROAD ' 'MAIN ' 'SITE ' 'NURS ' 'ESTB ' 'TEND ' 'PRUN '
                'PROT ' 'FELL ' 'SNIG ' 'HAUL ' 'HARVFC'

        'ENERGY-R1'
              16040.      162.      1268.    480.   640.    13.    112.    84.
        'ENERGY-R2'
                 0.       162.      1268.    480.   640.    26.    224.   126.

        'ENERGYHAV-SAW-R1'
              45.50    72.53     209.72       ( R1 = FIRST ROTATION
        'ENERGYHARV-SAW-R2'                     R2 = SECOND ROTATION )
              54.60    87.04     209.72
        'ENERGGHARV-PLP-R1'
             103.44    92.38      257.90
        'ENERGYHARV-PLP-R2'
             155.16   138.57      257.90
        'FCOM CONTRIB TO HARV'
           4.0

        'YEAR, R2 FRACTION IN PLANTINGS'
              1979.  0.12
              1985.  0.12
              1990.  0.15
              2000.  0.30
              2010.  0.85
          2015.  0.90
              2020.  0.95
              2030.  0.95

        'ANNUAL PLANT AREA'
              30000.
                          TONNES            FULLY
                   SAWLOG       PULPLOG     MECHANIZED
        1985      3347000.     4273000.      0.1
        1990      4516000.     5255000.      0.3
        2000      3308000.     5902000.      0.5
        2010     11231000.     6215000.      0.6
        2020     11794000.     6507000.      0.6


@FTN,CS ENERGY.PREDICT/JAM
FTN 10R1A  06/12/84-13:19(32,)
      C
      C     PROGRAM TO PREDICT THE FUTURE ENERGY REQUIREMENTS OF THE
      C     AUSTRALIAN FORESTRY ESTATE
      C
      C
              CHARACTER*6  OPCODE(12), GBG
              REAL ENERGY(2,8), EHSAW(2,3), EHPLP(2,3), LOGSUP(2,5),
           *  FRACR2(5), SUM(5), ENREQ(12,5), PLNT(2), SIZE(2),
           *  EOUT(3,5), RATIO(3,5)
              INTEGER YEARS(5)
      C
              COMMON /C1/ NPTS, YEAR(10), FCT(10)
      C
      C
      C        SCALING FACTOR  MJ --> TJ   (OUTPUT UNITS)
```

```
      DATA SCALE /1.0E+6/
      DO 1 JYR = 1,5
      DO 2 J = 1,12
    2 ENREQ(J,JYR) = 0.0
      DO 3 J = 1,3
      EOUT(J,JYR) = 0.0
      RATIO(J,JYR) = 0.0
    3 CONTINUE
      SUM(JYR) = 0.0
    1 CONTINUE
C
C
C
      INPT = 5
      READ(INPT,*) GBG, (OPCODE(J), J=1,12)
C
C  READ THE ENERGY FOR OPS 1..10 FOR R1 & R2
      READ(INPT,*) GBG,  (ENERGY(1,J), J=1,8)
      READ(INPT,*) GBG,  (ENERGY(2,J), J=1,8)
C
C  READ ENERGY FOR HARV OPS  R1 SAW, R1 PULP, R2 SAW, R2 PULP
C
      READ(INPT,*) GBG,( EHSAW(1,J), J=1,3)
      READ(INPT,*) GBG,(EHPLP(1,J), J=1,3)
      READ(INPT,*) GBG, (EHSAW(2,J), J=1,3)
      READ(INPT,*) GBG, (EHPLP(2,J), J=1,3)
C
C   READ THE ENERGY INPUT FROM FCOM,TONNE
      READ(INPT,*) GBG, FCOMEN
C
C   READ THE FRACTIONS OF R2 PLANTINGS IN VARIOUS YEARS
C   FIRST FIGURE IS NO OF DEFINED YEARS
C   FOLLOW WITH  (YEAR,FRACTION) PAIRS
C
      READ(INPT,*) GBG, NPTS, ( YEAR(J),PCT(J),J=1,NPTS)
C
C   READ THE  ANNUAL PLANTING AREA
      READ(INPT,*) GBG, PLTANN
C
C
C   READ FOR EACH YEAR TO BE PREDICTED
C    YEAR, SAWLOG DEMANDS, PULLOG DEMANDS, FRACT HARVESTED FROM R2
C
      DO 9 JYR = 1,5
      READ(INPT,*) YEARS(JYR),LOGSUP(1,JYR),LOGSUP(2,JYR), FRACR2(JYR)
    9 CONTINUE
C
C
      PLNT80 = 718272
C
C
      DO 100 JYR = 1,5
      YRNOW = YEARS(JYR)
      NOWYR = YRNOW + 0.1
C
C   COMPUTE THE SIZE OF THE TOTAL ESTATE
C
      ESTATE = PLNT80
      DO 30 J = 1981, NOWYR, 1
```

```
      R1PLNT = (1.0 - CFRACT( FLOAT(J))) * PLTANN
      ZZZ = CFRACT(FLOAT(J))
      WRITE(30,*) 'J =',J,'  CRFRACT=',ZZZ
 30   ESTATE = ESTATE + R1PLNT
C
C  COMPUTE THE AREAS OF IST & 2ND ROTATION IN THE ESTATE
      SIZE(2) = PLNT30 + (NOWYR-1980)*PLTANN  - ESTATE
      SIZE(1) = ESTATE - SIZE(2)
      PLNT(1) = R1PLNT
      PLNT(2) = PLTANN - PLNT(1)
C
C
C   COMPUTE THE TOTAL ENERGY NEEDS FOR EACH OPERATION
C
C    NON HARVESTING OPERATIONS
     DO 90 JJ = 1,2
C
      ENREQ(1,JYR) = ENREQ(1,JYR) + ENERGY(JJ,1)*PLNT(JJ)
C
      ENREQ(2,JYR) = ENREQ(2,JYR) + ENERGY(JJ,2)*SIZE(JJ)
C
      ENREQ(3,JYR) = ENREQ(3,JYR) + ENERGY(JJ,3)*PLNT(JJ)
C
      ENREQ(4,JYR) = ENREQ(4,JYR) + ENERGY(JJ,4)*PLNT(JJ)
C
      ENREQ(5,JYR) = ENREQ(5,JYR) + ENERGY(JJ,5)*PLNT(JJ)
C
      ENREQ(6,JYR) = ENREQ(6,JYR) + ENERGY(JJ,6)*SIZE(JJ)
C
      ENREQ(7,JYR) = ENREQ(7,JYR) + ENERGY(JJ,7)*SIZE(JJ)
C
      ENREQ(8,JYR) = ENREQ(8,JYR) + ENERGY(JJ,8)*SIZE(JJ)
C
C
C  HARVESTING OPERATIONS
C
      IF( JJ.EQ. 1)
     * THEN
         FRACT = 1.0 - FRACR2(JYR)
       ELSE
         FRACT = FRACR2(JYR)
      ENDIF
C
      ENREQ(9,JYR) = ENREQ(9,JYR) +
     $ FRACT * ( EHSAW(JJ,1)*LOGSUP(1,JYR) + EHPLP(JJ,1)*LOGSUP(2,JYR))
C
      ENREQ(10,JYR) = ENREQ(10,JYR) +
     $ FRACT * ( EHSAW(JJ,2)*LOGSUP(1,JYR) + EHPLP(JJ,2)*LOGSUP(2,JYR))
C
      ENREQ(11,JYR) = ENREQ(11,JYR) +
     $ FRACT * ( EHSAW(JJ,3)*LOGSUP(1,JYR) + EHPLP(JJ,3)*LOGSUP(2,JYR))
C
      ENREQ(12,JYR) = ENREQ(12,JYR) + (LOGSUP(1,JYR) + LOGSUP(2,JYR)) *
     *  FCOMEN
C
 90   CONTINUE
C
      SUM(JYR) = 0.0
      DO 95 J = 1,12
```

```
 95   SUM(JYR) = SUM(JYR) + ENREQ(J,JYR)
C
C
C     COMPUTE THE ENERGY OUTPUT OF THE ESTATE
C
      WOOD = LOGSUP(1,JYR)*0.42  +  LOGSUP(2,JYR)*0.37
      BARK = LOGSUP(1,JYR)*0.06   +  LOGSUP(2,JYR)*0.06
C
      EOUT(1,JYR) = WOOD*15700.0  +  BARK*17500.0
      EOUT(2,JYR) = EOUT(1,JYR) * 0.28
C
      EOUT(3,JYR) = EOUT(1,JYR) + EOUT(2,JYR)
C
      DO 97 J = 1,3
      RATIO(J,JYR) = EOUT(J,JYR) / SUM(JYR)
 97   CONTINUE
C
C        DEBUGGING  CODE FOR VERIFYING PROGRAM
C
      WRITE(6,*) ' INTERNAL DETAILS FOR YEAR =',YEARS(JYR)
      WRITE(6,*) 'TOTAL AREA OF ESTATE =',ESTATE
      WRITE(6,*) 'FIRST ROTATION AREA =',SIZE(1),
     *           'SECOND ROTATION AREA =',SIZE(2)
      WRITE(6,*) 'FIRST ROTATION PLANTING =',PLNT(1),
     *           'SECOND ROTATION PLANTING =',PLNT(2)
      WRITE(6,*) 'SECOND ROTATION LOG FRACTION =',FRACT
      WRITE(6,*) 'WOOD PRODUCTION =',WOOD
      WRITE(6,*) 'BARK PRODUCTION =',BARK
      WRITE(6,*) 'ENERGY DEMANDS =',SUM(JYR)
      WRITE(6,*) 'ENERGY PRODUCED =',(EOUT(JZ,JYR),JZ=1,3)
      WRITE(6,3000)
3000  FORMAT(//////)
C
 100  CONTINUE
C
      WRITE(6,2000)  (YEARS(J), J=1,5)
 2000 FORMAT(1H1, T3,'PREDICTED TOTAL ENERGY REQUIREMENT FOR NATIONAL',
     * ' SOFTWOOD PLANTATION ESTATE     (TERA JOULES)'///
     *   T3,'OPERATION', T22,5I15/)
C
      DO 120 J = 1,12
 120  WRITE(6,2001) OPCODE(J), (ENREQ(J,JYR)/SCALE , JYR=1,5)
      WRITE(6,*)
      WRITE(6,2001) 'TOTAL  ', (SUM(JYR)/SCALE , JYR=1,5)
 2001 FORMAT( T5,A6, T22,5F15.1)
C
C
      WRITE(6,2005)
 2005 FORMAT(1H1,T25,'ENERGY BALANCE OF NATIONAL FOREST ESTATE ',
     * ' ..     (TERA JOULES)'//)
C
      WRITE(6,2006) 'MERCH BOLES'
 2006 FORMAT(// A20 /T5,'YEAR', T22,'GROSS OUT', T37,'INPUT',
     * T52,'NET YIELD', T67,'RATIO',)
      DO 125 JYR = 1,5
 125  WRITE(6,2007) YEARS(JYR), EOUT(1,JYR)/SCALE, SUM(JYR)/SCALE,
     *     (EOUT(1,JYR)-SUM(JYR))/SCALE, RATIO(1,JYR)
 2007 FORMAT(/T5,I4, T15, 3F15.2, F10.1,':1')
C
```

```
      WRITE(6,2006) 'NON MERCH BOLES + STUMPS'
      DO 130 JYR = 1,5
  130 WRITE(6,2008) YEARS(JYR), EOUT(2,JYR)/SCALE
 2008 FORMAT(/T5,I4, T45, F15.2)
C
      WRITE(6,2006) 'TOTAL'
      DO 140 JYR = 1,5
  140 WRITE(6,2009) YEARS(JYR), SUM(JYR)/SCALE,
     *    (EOUT(3,JYR)-SUM(JYR))/SCALE
 2009 FORMAT(/T5,I4, T30, 2F15.2)
      STOP
      END


      REAL FUNCTION CFRACT( TYEAR )
C
C     FUNCTION TO PERFORM LAGRANGIAN INTERPOLATION TO
C     PREDICT THE FRACTION OF PLANTING TO BE R2 IN A GIVEN YEAR
C
C
      COMMON /C1/ NPTS, YEAR(10), PLT(10)
C
C
      PROD = 0.0
      DO 10 J = 1,NPTS
      COEFFN =1.0
      COEFFD = 1.0
      DO 20 JJ = 1,NPTS
      IF( JJ .NE. J)
     *  THEN
          COEFFN = COEFFN * (TYEAR - YEAR(JJ))
          COEFFD = COEFFD * (YEAR(J) - YEAR(JJ))
      ENDIF
   20 CONTINUE
   10 PROD = PROD + COEFFN/COEFFD * PCT(J)
C
  900 CFRACT = PROD
      RETURN
      END
```

```
@FTN,C Q.PREDICT/JAM1
FTN 10R1A  05/13/84-18:51(3,)

END FTN 509 IBANK 969 DBANK 21 COMMON

   ENTERING USER PROGRAM
 INTERNAL DETAILS FOR YEAR =          1985
TOTAL AREA OF ESTATE =  850272.00
FIRST ROTATION AREA =  832272.00     SECOND ROTATION AREA =  18000.000
FIRST ROTATION PLANTING =  23400.000    SECOND ROTATION PLANTING =  3599.9993
SECOND ROTATION LOG FRACTION =  .10000000+000
WOOD PRODUCTION =  3221040.0
BARK PRODUCTION =  457200.00
ENERGY DEMANDS =  .36005909+010
ENERGY PRODUCED =  .61792367+011  .17301363+011  .79094229+011



 INTERNAL DETAILS FOR YEAR =          1990
TOTAL AREA OF ESTATE =  979572.00
FIRST ROTATION AREA =  940872.00     SECOND ROTATION AREA =  38700.000
FIRST ROTATION PLANTING =  25500.000    SECOND ROTATION PLANTING =  4499.9993
SECOND ROTATION LOG FRACTION =  .30000000
WOOD PRODUCTION =  4157190.0
BARK PRODUCTION =  556260.00
ENERGY DEMANDS =  .47416176+010
ENERGY PRODUCED =  .79584621+011  .22311594+011  .10199631+012



 INTERNAL DETAILS FOR YEAR =          2000
TOTAL AREA OF ESTATE =  1209822.0
FIRST ROTATION AREA =  1101372.0     SECOND ROTATION AREA =  108450.00
FIRST ROTATION PLANTING =  21000.000    SECOND ROTATION PLANTING =  9000.0000
SECOND ROTATION LOG FRACTION =  .50000000
WOOD PRODUCTION =  6254659.9
BARK PRODUCTION =  852600.00
ENERGY DEMANDS =  .69000549+010
ENERGY PRODUCED =  .11937332+012  .33424529+011  .15279785+012



 INTERNAL DETAILS FOR YEAR =          2010
TOTAL AREA OF ESTATE =  1329072.0
FIRST ROTATION AREA =  1039871.9     SECOND ROTATION AREA =  289200.03
FIRST ROTATION PLANTING =  4500.0001    SECOND ROTATION PLANTING =  25500.000
```

```
SECOND ROTATION LOG FRACTION =   .60000000
WOOD PRODUCTION =   7327239.9
BARK PRODUCTION =   1049760.0
ENERGY DEMANDS =   .83056675+010
ENERGY PRODUCED =   .14903571+012   .41743997+011   .19082970+012


 INTERNAL DETAILS FOR YEAR =          2020
TOTAL AREA OF ESTATE =  1357572.0
FIRST ROTATION AREA =  796871.91     SECOND ROTATION AREA =  560700.05
FIRST ROTATION PLANTING =  1499.9999     SECOND ROTATION PLANTING =  26500.000
SECOND ROTATION LOG FRACTION =   .60000000
WOOD PRODUCTION =   8185649.9
BARK PRODUCTION =   1093050.0
ENERGY DEMANDS =   .86644952+010
ENERGY PRODUCED =   .15593310+012   .43651268+011   .19959437+012
```

Appendix Table A.19 Second Rotation Planting, Tumut Sub-division (ha)

1978	72
1979	109
1980	148
1981	176
1982	120
1983	74
1984	199

Appendix A.20 Primary energy inputs to plantation forestry (from Wells, 1984).

Tracing primary sources

An energy absorption matrix consisting of 109 sectors of the economy by 7 primary and 14 secondary energy products has been compiled by James (1980) from the 1968/69 Australian input-output tables. This matrix has been used to calculate the proportional contribution of primary energy sources to the input categories fuel, repairs, goods, steel and labour. A matrix developed from more recent (1974/75) input-output tables has since become available (James et al., 1982) but, unfortunately, this has had to be condensed to 49 'super' sectors. It is therefore not amenable to use the same way as the matrix in James (1980). Some of the assumptions made when calculating proportional contribution by primary sources of energy to the five input catogories for a full rotation are noted below.

Fuel. Petrol, diesel, lubricating oil and grease has been assumed to be 100% oil-based.

Repairs. Repairs fall into the industrial sectors 'repairs to motor vehicles' and 'rubber goods' (includes tyres). Energy expenditure in each of these is assumed to be in the same proportion as found for Tumut in 1977/78.

Goods. A variety of sectors were represented in the goods used in Tumut in 1977/78; the proportional contribution of primary energy was computed for this mix of goods. Electricity, which was considered a service, was split 82% coal, 5% oil, 5% wood and bagasse, and 8% hydroelectricity (Hawkins, 1976).

Steel. Machine fabrication was considered to comprise the sectors 'motor vehicle manufacture', 'construction and earthmoving machinery and equipment' and 'other machinery and equipment'.

Labour. Indirect energy in food consumed in Australia in 1974/75 was separated as per Watt (1980) into that used in: (a) agriculture; (b) transport; (c) food processing; (d) packaging; (e) retailing; (f) cooking; and (g) refrigeration. Sources of energy for cooking were taken as 65% electricity, 30% gas, 5% wood (1976 Census). Primary sources of energy for home refrigeration were assumed to be 78% coal, 3% oil, 3% wood and bagasse, 6% hydro and 10% natural gas. Other allocations to primary sources were made for the appropriate sectors. Direct energy in food, not being a primary source of commercial energy and, anyway, contributing a small proportion (less than one-sixth) of the total energy in this category, was ignored.

Primary sources

The percentage contribution by different primary energy sources to each energy input category, based on use of the energy absorption matrix for 1968/69, is shown in Table V. Coal includes black and brown coal; wood includes wood and bagasse. Figure 2, consisting of bar histograms depicting the annual energy input per ha by input category and, further, by primary sources (using formation from Table V), clearly shows how dominant is the position of oil as a primary source of energy for plantation forestry. More

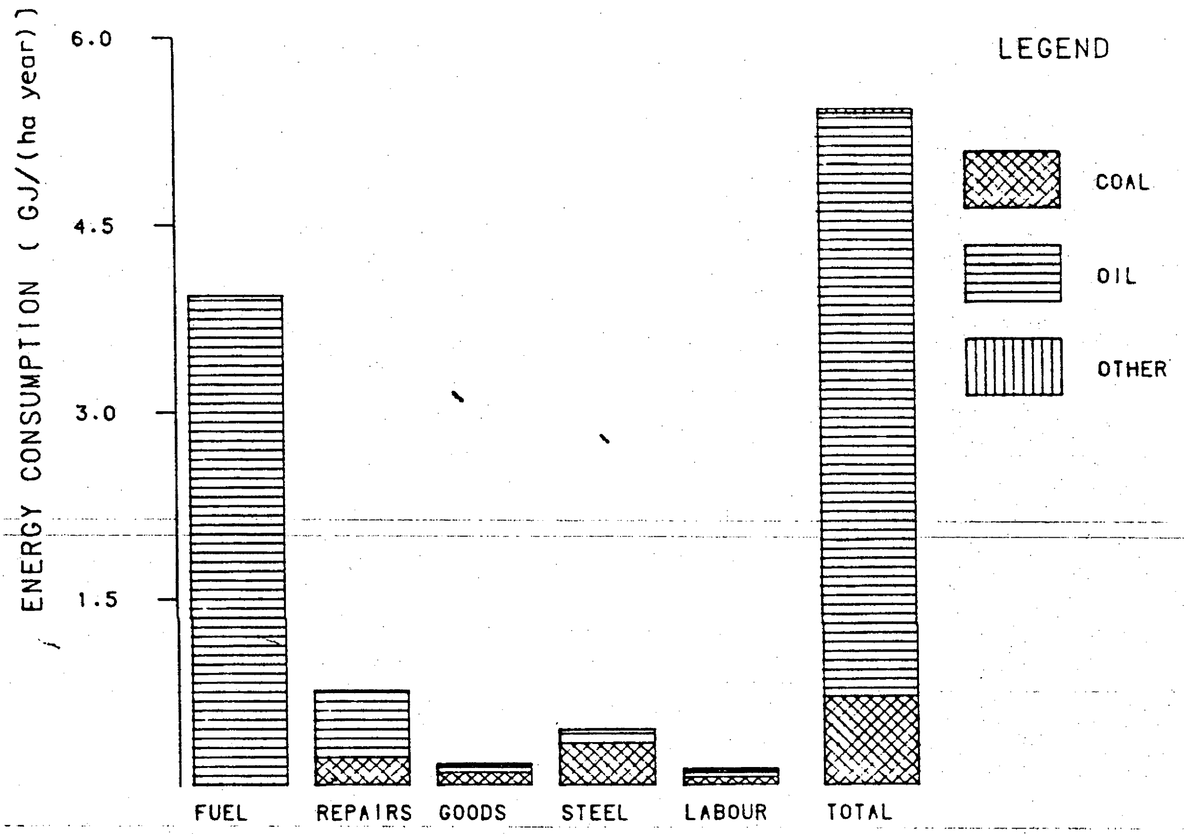


Fig. 2. Annual energy requirements per ha showing primary sources of energy for each input energy. (Tumut).

TABLE V

Primary energy sources involved in growing and harvesting radiata pine plantations expressed as percent of total energy in each input category

	Coal	Oil	Wood	Hydro	Gas	Total
Fuel	0	100	0	0	0	100
Repairs	29	70	—	1	0	100
Goods	58	37	2	3	—	100
Steel	75	24	0	1	0	100
Labour	46	43	3	2	6	100

than 86% (4.6 GJ) of the total energy requirement is satisfied by oil, 13% (0.7 GJ) by coal, and less than one percent from other sources. Most of the oil energy is consumed directly as fuel (3.9 GJ) but a surprising amount (0.5 GJ) is consumed indirectly in repairs. Most of the coal-derived energy is consumed indirectly in steel and fabrication of machines (0.3 GJ) and in repairs (0.2 GJ).