

2 Methodology

2.1 Rationale for the input–output approach

Much of the ecological footprint work undertaken to date has been based on methodologies that lack formal structure. Some approaches may even be considered to be ad hoc. A major limitation of such methods is that they may lead to results that are not easily reproduced either through time or across space. In turn, this restricts comparability or leads to inconsistencies that are more an artefact of the method rather than actual differences. Such concerns led Bicknell et al (1998) to develop an alternative formulation of the ecological footprint calculation based on input–output analysis.

Input–output analysis, developed by Wassily Leontief during the 1930s, provides a comprehensive snapshot of the structure of inter-industry linkages in an economy. Most developed nations prepare input–output tables at regular intervals. Generally speaking, an input–output table of a nation is conceptually reconcilable with its system of national accounts (SNA). In addition, input–output tables adopt internationally recognised systems of commodity/industry classification (eg. the International Standard Industrial Classification (ISIC)). This facilitates comparison over time, between nations and with standard economic aggregates such as GDP and Balance of Trade.

Although input–output tables are usually presented in monetary terms, authors such as Daly (1968), Isard (1968), Leontief (1970) and Victor (1972) have demonstrated that biophysical information on resource use and pollution generation may also be placed in an input–output framework. A major strength of input–output analysis is that it may be used to calculate the indirect effects of economic change, including indirect effects relating to resource use and pollution generation if this information is included in the input–output table.

The advantages of using the input–output method in calculating the ecological footprint are:

- (1) It is a more comprehensive method covering a wider range of inputs than the ad hoc methods. Typically, for example, ad hoc methods tend to ignore service sector inputs (banking, insurance) all of which have significant embodied land inputs. This neglect of several categories of inputs typically reduces the magnitude of the calculated ecological footprint. The mathematics of the input–output analysis also means that the first, second, third ... nth round effects (infinite regress) can be more accurately and comprehensively calculated.
- (2) It is a systematic method. The input–output matrices provide a convenient checklist to ensure that all flows in the economy are taken into account. The conservation principles (inputs = outputs) of input–output accounting further ensures that there are no unintentional blind spots, as all inputs and outputs must be taken account of.
- (3) Input–output analysis avoids a number of methodological problems – in other words:
 - (a) double-counting is a problem in ad hoc methods particularly when dealing with complicated networks of indirect flows that have significant feedbacks. This type of problem is generally overcome by using input–output analysis
 - (b) joint production causes problems when using ad hoc methods due to the need to allocate land inputs across multiple outputs of commodities from a process – joint production matrices of the type used by Costanza and Hannon (1989) overcome this problem.

- (4) It is a mathematically rigorous method. The use of matrix algebra is not only efficient in dealing with large datasets but also enables the analysis to be undertaken in an internally consistent mathematical framework.

The disadvantages in using the input–output method for calculating ecological footprints are:

- (1) The input–output sector categories are often too broad which can lead to inaccurate results. For example, the type of food consumed by a person (ie. diet) is a well-known determinant of the size of that person’s ecological footprint. The input–output matrices usually do not provide enough disaggregation into different food types to take account of these dietary differences – typically there might be only one input–output sector category ‘food’ that does not even distinguish between meat and vegetable consumption.
- (2) Accurate and up-to-date input–output matrices often do not exist for a nation or a region. For example, in New Zealand accurate national-level input–output tables are only produced on a five-yearly basis, and there is often a delay of up to five years before they are published. This could be problematical, particularly if there has been rapid technological or structural change in the economy over the intervening years. Survey-based regional input–output tables do not exist in New Zealand, and they have to be estimated using non-survey methods (eg. like the GRIT method).
- (3) The inter-industry linkages in an economy generally represent flows of physical goods. In input–output analysis such flows are usually summarised in a transactions table denominated in monetary units. Certainly, monetised transaction tables are widely available both at the national and regional levels, which facilitates the widespread application of the methodology described in Sections 2.2 and 2.3. However, the use of monetised tables can lead to problems if the price paid for a given product differs across purchasing industries. If Industry 1, for example, purchases 10 kg of goods at 20 cents per kg and Industry 2 purchases 10 kg of goods at 10 cents per kg from the same industry, then both industries receive the same physical quantity of goods 10 kg, but spend different amounts, \$2.00 and \$1.00 respectively. This implies from a monetary transaction perspective, that the land embodied in Industry 1 purchases is twice that of Industry 2 purchases – whereas, from a physical perspective both industries are purchasing the same physical quantity of goods. This effect may result in both under- and over-estimation of sector contributions made to the ecological footprint. This problem can be overcome, using various mixed price methods, if the price deficiencies across industries are known.

2.2 Methodology for measuring New Zealand’s ecological footprint

As noted above this report uses an input–output based methodology to calculate the New Zealand ecological footprint. This method was first devised and applied at Lincoln University by Bicknell et al (1998), using New Zealand as a case study. Rather than repeat this methodology here, a summary of the main procedural steps is provided below. Readers interested in the strict technical aspects of this method are directed to Bicknell et al (1998).

The method is developed in two parts. In the first part the domestic land embodied in goods and services consumed by the New Zealand population is determined. The second part extends the first part to include land embodied in products purchased from overseas and removes the land embodied in products sold overseas. In broad terms, the method requires the calculation of input–output coefficients that are subsequently multiplied by land to value-of-output ratios on a sector by sector basis. Multiplying the elements of the resulting matrix (expressed in hectares

per dollar of output) by a vector of final demand (consumption) determines the land supporting the New Zealand population.

2.2.1 Domestic land calculation

Step A: Calculation of the technical coefficient matrix

The procedure begins with a standard New Zealand inter-industry (input–output) table. A technical coefficient matrix is derived from the New Zealand inter-industry table by dividing each table element by its corresponding industry gross input/output total. The technical coefficient matrix **A** shows the amount of inputs in monetary terms that row sector *i* needs to increase output in column sector *j* by one monetary unit. Such purchases, which are ultimately driven by consumer demand for final goods and services, initiate a chain of economic activity throughout the productive sectors of the economy.

Step B: Calculation of the Leontief inverse matrix

The total repercussionary effects associated with all chains of economic activity in an economy may be summarised by calculation of the Leontief inverse matrix. Calculation of the Leontief inverse matrix requires:

- (1) the technical coefficients matrix **A** be subtracted from an identity matrix **I**
- (2) that the result of this calculation be inverted to obtain $(\mathbf{I}-\mathbf{A})^{-1}$.

Each element in this matrix represents the amount of economic activity generated for row industry *i*, both directly and indirectly, to increase output in column industry *j* by one monetary unit.

Step C: Calculation of land multipliers

The land area required to increase output in each industry by a particular monetary amount is then calculated. This requires the total land area occupied by each sector of the New Zealand economy (expressed in hectares) to be divided by the corresponding industry's total gross input/output (column total) figure. The resulting ratios are referred to as 'land multipliers', and represent the number of hectares required to increase output by one monetary unit in each column industry.

Step D: Calculation of embodied land requirements

Total embodied (direct plus indirect) land requirements can then be obtained by premultiplying the Leontief inverse matrix by a diagonal matrix containing the New Zealand land multipliers. Column totals of the resulting matrix represent the total number of hectares required to increase output in each column industry by one monetary unit.

Step E: Calculation of the land required to meet domestic final demand

The land required to meet current levels of domestic final demand for each industry can be derived by multiplying total land input requirements for each industry (as calculated in Step D) by the corresponding component of the final demand vector. This provides a ‘first’ estimate of New Zealand’s ecological footprint. Two additional steps are required to generate the ‘final’ estimate, namely:

- (1) energy land needs to be added
- (2) land embodied in goods/services purchased from overseas be added, and conversely, land embodied in goods/services sold overseas be subtracted.

These are dealt with below.

Step F: Calculation of energy land component of the ecological footprint

Energy land represents the hypothetical land needed to sequester the CO₂ emissions resulting from the burning of fossil fuels. Fossil fuels are used in New Zealand for a wide range of economic activities including electricity generation, fuel for our cars, production of plastics, rubber and numerous other goods. The energy land required to sustain a population is easily calculated using an input–output approach, mirroring the process described above for domestic land component of the ecological footprint. Specifically, all that is required in the calculations is the substitution of energy multipliers for land multipliers. Total fossil fuel use by each industry in the New Zealand was determined by using data obtained from the ECCA Energy End-Use Database. The multipliers were in turn calculated by dividing the fossil fuel usage (by type) by each column industry’s gross output (column) total. Domestic fossil fuel requirements (by type) were then derived in an analogous way to domestic land requirements (ie. by repeating Steps D and E using the energy information).

Conversion of fossil fuel into hypothetical land equivalents required two conversions. Firstly, the domestic fossil fuel requirements (by type) were converted to CO₂ emissions using appropriate emission factors. Secondly, CO₂ emissions were expressed in land equivalent terms using a sequestration rate for *Pinus radiata*. In this way, energy land represents a hypothetical estimate of the area of planted forest needed to absorb the CO₂ emissions resulting from the use of fossil fuels by New Zealanders.

2.2.2 Dealing with land embodied in overseas trade

In a closed economy (ie. without trade) the above analysis would be satisfactory. Trade with other countries, however, means that New Zealanders consume land (and energy) embodied in the goods and services they purchase from overseas. Conversely, New Zealanders export land (and energy) embodied in the goods and services they sell abroad. One further adjustment is therefore required to complete the calculation of New Zealand’s ecological footprint.

Step G: Calculation of land embodied in overseas trade

The lack of availability of information on overseas land use by economic sector makes the analysis of land embodied in imports difficult. By assuming similar production technologies however it is possible to derive crude estimates. In this way, the land (and energy land) embodied in goods and services purchased abroad by final demand may be calculated by multiplying the value of imports by its corresponding domestic land (or energy) multiplier.

The process of calculating the land embodied in imports used by intermediate demand (industries in the New Zealand economy) and then sold onto final demand is, however, more difficult. This requires a detailed breakdown of the imports to each productive column industry. In this matrix, columns represent the domestic purchasing industry, and rows represent the overseas producing industry, with all elements expressed in monetary terms. Once again, the conversion to hectares would ideally require detailed information from each country providing intermediate inputs. Such information is however not available but crude estimates can be established using the New Zealand economy as a proxy. The land embodied in imports used by intermediate demand is derived in turn by premultiplying the matrix of imports by the vector of embodied (direct plus indirect) land requirements for the New Zealand economy. It is implicitly assumed that the goods are in near finished state ready for final demand consumption.

It is important to recognise that some of the land (and energy land) embodied in New Zealand's imported goods and services will, in turn, be exported abroad. In other words, only a fraction of the land embodied in imported products will support New Zealand's domestic final demand. The land embodied in imported products for each industry is therefore multiplied by the fraction of final demand that is consumed domestically.

The 'final' estimate of New Zealand's ecological footprint is then calculated by adding:

- (1) the domestic land embodied in products consumed locally (from Step E)
- (2) domestic energy land required to sequester CO₂ emissions embodied in products consumed locally (from Step F)
- (3) the land (and energy land) embodied in products purchased overseas but consumed locally (Step G).

The ecological footprint for the entire economy may then be converted to a per capita basis by dividing by the New Zealand population.

2.3 Methodology for measuring regional ecological footprints

2.3.1 Accounting identity of the component parts of the ecological footprint

In this report an approach is presented that:

- (1) provides a formal structure for ecological footprint calculations
- (2) permits calculation of the ecological footprint at a regional (sub-national) level
- (3) makes explicit interregional appropriation of biologically productive land.

Essentially, the method requires the calculation of ecological footprint land contributions as defined by the following accounting identity:

$$EF \equiv \alpha + (\beta_1 + \beta_2 + \dots + \beta_n) + \delta \quad (1)$$

where:

α = land appropriated from within the study region

$\beta_1 + \beta_2 + \dots + \beta_n$ = land appropriated from other regions (1 ... n)

δ = land appropriated from other countries

The method is illustrated using a three-sector hypothetical regional economy – termed the study region.

2.3.2 Generation of regional input–output tables

The method begins with calculation of input–output tables for the study region and for all the other regions it trades with. These tables were derived using the GRIT (Generation of Regional Input Output Tables) system developed by Jensen et al (1979) and West et al (1980).⁸ This method consists of a series of mechanical steps that reduce national input–output coefficients to sub-national (regional) equivalents while providing opportunities for the insertion of ‘superior data’.⁹ It is most frequently utilised, as in this report, when time, cost and data constraints preclude generation of regional input–output tables based on survey data.

2.3.3 Estimation of land appropriated within the region

Step One: Calculation of the Leontief Inverse

Determining the land appropriated from within the region α begins with calculation of a technical coefficients matrix \mathbf{A} . This matrix is derived by dividing each element in a transactions matrix \mathbf{Ax} (Table 2.1), by its associated output \mathbf{x} . The resulting technical coefficients matrix \mathbf{A} (Table 2.2), represents the direct inputs from row sector i required to increase column sector j by an additional dollar (eg. the agriculture sector requires a \$0.19 direct purchase from the services sector). The contribution made by a sector to an economy is not solely limited to the value it creates directly – an increase in final demand in a sector has repercussions throughout the entire economy, causing indirect increases in output beyond the initial change in final demand. Such repercussions are captured in the Leontief Inverse Matrix $(\mathbf{I} - \mathbf{A})^{-1}$.

⁸ Studies that have applied the GRIT method in New Zealand include Hubbard and Brown (1981), Butcher (1985), Kerr, Sharp and Gough (1986) and the Ministry of Agriculture (1997).

⁹ Data considered by the implementing analyst to be more reliable than those produced by the mechanical process (Jensen et al, 1979).

Table 2.1 Transactions matrix for the hypothetical study region

	Agriculture	Manufacturing	Services	Domestic final demand	Interregional exports	International exports	Total output
Agriculture	606	1,214	46	99	486	350	2,801
Manufacturing	184	748	700	1,213	83	1,997	4,925
Services	543	854	2,628	4,793	106	505	9,429
Value added	1,312	1,357	5,415	621	0	52	8,758
Interregional imports	10	64	60	142	0	0	276
International imports	145	688	580	1,130	0	0	2,543
Total input	2,801	4,925	9,429	7,998	675	2,905	28,732
Land input (ha)	1,883,800	2,900	120,000	2,031,200			
CO ₂ input (t)	332,700	1,956,800	701,200	4,168,200			

Note: All values are expressed in millions of dollars unless otherwise stated.

Table 2.2 Technical coefficients matrix for the hypothetical study region

	Agriculture	Manufacturing	Services
Agriculture	0.216	0.247	0.005
Manufacturing	0.066	0.152	0.074
Services	0.194	0.173	0.279

Note: All values are in dollars per year.

The Leontief inverse matrix $(\mathbf{I} - \mathbf{A})^{-1}$ is derived by subtracting the matrix of technical coefficients \mathbf{A} from an identity matrix \mathbf{I} of the same dimensions and inverting the result. Each element represents the direct and indirect economic requirements in row sector i needed to generate an additional unit of output in column sector j . For example, a dollar increase in the service sector final demand will require \$0.05 of the agriculture sector output (refer to Table 2.3).

Table 2.3 Leontief inverse matrix for the hypothetical study region

	Agriculture	Manufacturing	Services
Agriculture	1.322	0.394	0.050
Manufacturing	0.136	1.245	0.129
Services	0.388	0.405	1.431

Note: All values are in dollars per year.

Step Two: Determination of the direct and indirect land requirements for each sector

The embodied (direct plus indirect) land required to increase final demand in each sector by an additional unit is calculated as follows. Firstly, land-to-output ratios (known as land coefficients) are obtained by dividing the total land use in each sector by its corresponding total output (eg. the land coefficient for the agriculture sector is 672.55 ha \$m⁻¹ (1,883,800 ha ÷ 2801 \$m)). Secondly, these coefficients are then diagonalised to form the matrix $\hat{\mathbf{B}}$. Finally, embodied land requirements \mathbf{C} are calculated by premultiplying the Leontief Inverse matrix by the diagonalised matrix of land coefficients:

$$\mathbf{C} = \hat{\mathbf{B}}(\mathbf{I} - \mathbf{A})^{-1} \quad (2)$$

Results for the hypothetical study region are shown in Table 2.4. This analysis provides a deeper appreciation of the land requirements of sectors, particularly for those that initially appear not to be intensive land users. For example, to produce a million dollars of final demand the manufacturing sector requires not only 0.73 ha of manufacturing land but also indirectly requires 265.13 ha of agricultural land.

Table 2.4 Matrix of direct plus indirect land requirements for the hypothetical study region

	Agriculture	Manufacturing	Services
Agriculture	888.71	265.13	33.30
Manufacturing	0.08	0.73	0.08
Services	4.94	5.16	18.21

Note: All values are in ha \$m⁻¹ per year of final demand.

Step Three: Apportion direct and indirect land requirements between domestic final demand and exports

Not all of the land appropriated supports domestic consumption. A portion passes out of the study region as land embodied in exports. The land supporting domestic final demand \mathbf{E} is calculated by multiplying the matrix of direct plus indirect requirements \mathbf{C} by a matrix representing domestic final demand $\hat{\mathbf{D}}$. Thus:

$$\mathbf{E} = \mathbf{C}\hat{\mathbf{D}} \quad (3)$$

The domestic final demand matrix $\hat{\mathbf{D}}$ is obtained by diagonalising the ‘domestic final demand’ column of Table 2.1. Results for the hypothetical study region are shown in Table 2.5. Domestic final demand for manufactured products in the study region requires the appropriation of 321,725 ha of agricultural land, 890 ha of manufacturing land and 6261 ha of service sector land.

Table 2.5 Within-region land supporting domestic final demand for the hypothetical study region

	Agriculture	Manufacturing	Services
Agriculture	87,566	321,725	159,597
Manufacturing	8	890	364
Services	487	6,261	87,271
Total	88,061	328,876	247,232

Note: All values are in ha per year.

Step Four: Repeat Steps One to Three for the calculation of energy land

Energy land represents the area of planted forest needed to sequester CO₂ emissions resulting from the burning of fossil fuels. The approach used to calculate energy land appropriated within the region is analogous to that used to calculate the within-region land supporting domestic final demand. Essentially, there are two differences:

- (1) CO₂ coefficients are used instead of land coefficients
- (2) total embodied CO₂ emissions are converted into planted forest using a *Pinus radiata* sequestration rate of 0.0758 ha per t of CO₂.

Within region appropriation of energy land by the study region is shown in Table 2.6.

Table 2.6 Within region energy land supporting domestic final demand for the hypothetical study region

	Agriculture	Manufacturing	Services
Agriculture	1,172	4,307	2,137
Manufacturing	404	45,502	18,628
Services	216	2,773	38,656
Total	1,792	52,582	59,421

Note: All values are in ha per year.

Step Five: Calculation of the total within region appropriated land (δ)

Summing the column totals in Tables 2.5 and 2.6 provides an estimate of the quantity within-region land required to meet current levels of domestic final demand for each sector. Domestic final demand for manufactured goods requires a total land appropriation of 381,458 ha (328,876 ha + 52,582 ha, for the manufacturing sector column totals in Tables 2.5 and 2.6).

2.3.4 Estimation of land appropriated from other regions

Land embodied in interregional trade may have a considerable influence on the size of the ecological footprint, particularly if the ecological footprint is being calculated for an urban region. It is argued here that not only must the size of such a contribution be known but also the locations from where it originated. Adjustments can then be made for differences in biological productivity resulting from land management practices and environmental factors such as soil type, climatic conditions and so on. In this way, significantly improved interpretations of the ecological footprint are possible. An approach is developed here that not only calculates the interregional land appropriated, but also attributes each appropriation to its region of origin. This approach is illustrated using the three hypothetical regions that share ecological interdependencies with the study region (refer to Table 2.7).

Table 2.7 Imports for three hypothetical regions

	Agriculture	Manufacturing	Services	Domestic final demand	Region total
Region 1					
Agriculture	0.1	0.6	0.0	0.0	0.7
Manufacturing	0.2	19.4	6.6	5.9	32.1
Services	3.9	5.7	28.3	76.9	114.8
Region 2					
Agriculture	0.5	2.9	0.1	0.0	3.5
Manufacturing	0.1	5.7	1.9	1.7	9.4
Services	2.8	4.1	20.4	55.4	82.7
Region 3					
Agriculture	2.9	19.0	0.5	0.0	22.5
Manufacturing	0.1	6.4	2.2	2.0	10.7
Services	0.0	0.0	0.0	0.0	0.0

Note: All values are in \$m per year.

Step Six: Determination of interregional flows

In order to estimate the land appropriated from other regions, the interregional flows of commodities between regions had to be first of all calculated. In the analysis reported in Sections 4 to 19 of this report, these flows needed to be determined at the 23 sector level – hence, there were 5520 possible flows (16 regions x (16-1) regions x 23 sectors). Unfortunately, interregional flow data at this level of detail is not available from statistical sources in New Zealand but could be estimated using an optimisation method which is described in Appendix A.

Minimisation of travel time is set as the objective function while known levels of imports/exports for each sector (by region) are used to formulate binding constraints.¹⁰ This optimisation approach could also be used in any other country which lacks interregional flow (\$) data. The origins of imports for the hypothetical study region, as generated by this optimisation, are shown in Table 2.7.

Step Seven: Determination the direct and indirect land and energy land appropriated from other regions

The land (and energy land)¹¹ embodied in interregional imports is derived by premultiplying the imports (Table 2.7) by the direct plus indirect land requirements needed to make them (Table 2.8). This is performed for each region sharing ecological interdependencies with the study region:

$$\mathbf{K} = \mathbf{G} \mathbf{H} \quad (4)$$

where \mathbf{K} = land matrix ($i \times j$) which describes the land appropriated from i sector to j sectors for a given region; \mathbf{G} = Leontief inverse matrix ($i \times j$) which describes the direct plus indirect requirement \mathbf{I} into j sectors, for a given region; \mathbf{H} = imports ($i \times j$) which describes the inputs into j sectors for a given region. It is assumed here that imported goods and services are essentially final or finished goods. This implies that only backward linkages through the economy in the region of origin are measured. If, however, there are imported goods requiring further processing in the study region, then forward linkages may also need to be estimated.

Table 2.8 Direct plus indirect land requirements for the hypothetical study region

	Agriculture	Manufacturing	Services
Region 1			
Agriculture	860.6	62.2	9.2
Manufacturing	0.0	0.5	0.1
Services	0.7	0.9	3.0
Region 2			
Agriculture	1344.8	240.7	30.2
Manufacturing	0.1	0.7	0.1
Services	3.5	3.6	12.4
Region 3			
Agriculture	1899.5	504.6	71.9
Manufacturing	0.2	1.4	0.2
Services	3.3	3.6	11.4

Note: All values are in ha \$m⁻¹ per year of final demand.

¹⁰ This optimisation model assumes that transport operators will only minimise their travel times, whereas in actuality other factors may also come into play. This approach however doesn't seem unreasonable and it is very commonly used in transportation network models. Furthermore, analytical tests show that the optimisation problem is relatively constrained, therefore having a small feasibility space which means that there will not be a too significant difference between the 'optimal' and 'actual' flows.

¹¹ The calculation of energy land is based on 'direct plus indirect energy land' rather than 'direct plus indirect land'.

The land embodied in interregional imports appropriated by the hypothetical study region is shown in Table 2.9. The manufacturing sector, for example, appropriates 46,711 ha (manufacturing column total in Table 2.9). This is comprised of 46,482 ha of agricultural land (1773 ha for Region 1 + 5448 ha Region 2 + 39,261 ha for Region 3).

Table 2.9 Land appropriated from other regions for the hypothetical study region

	Agriculture	Manufacturing	Services	Domestic final demand
Region 1				
Agriculture	129	1,773	685	1,079
Manufacturing	0	10	5	8
Services	12	36	91	237
Region 2				
Agriculture	713	5,448	1,187	2,094
Manufacturing	0	4	3	5
Services	36	82	260	693
Region 3				
Agriculture	5,611	39,261	2,114	1,042
Manufacturing	1	12	3	3
Services	10	85	10	7
Sector totals	6,512	46,711	4,357	5,168

Note: All values are in ha per year.

Step Eight: Apportion direct and indirect land requirements between domestic final demand and exports

Not all of the interregional land appropriated supports domestic consumption. A portion passes out of the study region as land embodied in exports. The fraction of final demand supporting domestic consumption is derived from Table 2.1 (ie. 36.8 percent of manufactured products,¹² 10.5 percent of agricultural products and 88.7 percent of services). Multiplying interregional land appropriated \mathbf{K}_r by the fraction of final demand $\hat{\mathbf{L}}$ calculates the interregional land supporting domestic consumption \mathbf{M}_r :

$$\mathbf{M}_r = \mathbf{K}_r \hat{\mathbf{L}} \quad (5)$$

where $\hat{\mathbf{L}}$ is a diagonalised matrix containing the fractions of final demand consumed locally.¹³ Interregional land supporting domestic consumption in the hypothetical study region is shown in Table 2.10. Summing the final column (or row) of Table 2.10 determines the total amount of land appropriated from other regions ($\beta_1 + \beta_2 + \dots + \beta_n$) (ie. 26,929 ha which represents 0.07 ha per capita).

¹² Calculated by dividing domestic final demand for manufactured products by total final demand for manufactured products (ie. $(1213 \div (1213 + 83 + 1997)) \times 100$).

¹³ The number 1 is placed in the bottom right hand corner of matrix $\hat{\mathbf{L}}$ so that land appropriated directly by domestic final demand is included.

Table 2.10 Land appropriated from other regions supporting domestic consumption for the hypothetical study region

	Agriculture	Manufacturing	Services	Domestic final demand	Region total
Region 1					
Agriculture	14	653	607	1,079	2,353
Manufacturing	0	4	5	8	16
Services	1	13	81	237	332
Region 2					
Agriculture	75	2,007	1,053	2,094	5230
Manufacturing	0	2	2	5	9
Services	4	30	230	693	957
Region 3					
Agriculture	591	14,465	1,875	1,042	17,974
Manufacturing	0	4	3	3	10
Services	1	31	8	7	48
Sector totals	687	17,210	3,865	5,168	26,929

Note: All values are in ha per year.

2.3.5 Estimation of land appropriated from other nations (δ)

The availability of land (and energy land) data is a major issue when determining the amount of land appropriated internationally. Ideally this would involve the acquisition of detailed information by economic sector from each international trading partner. In this report it is assumed that the direct and indirect land required to produce one dollar's worth of product from a sector is exactly the same internationally as it is nationally. This in turn implies that the technologies, land management practices and sectoral interlinkages are similar between the nation and its international trading partners which may not be the case. In this way, crude estimates of the land (and energy land) embodied in international imports can be made. The approach is demonstrated here using a hypothetical national economy – an actual national input–output matrix with land inputs and CO₂ emissions for this economy is available from the authors.

Step Nine: Calculation of the land appropriated from other nations

The calculation procedure is analogous to that employed for interregional trade. Firstly, international imports matrix \mathbf{O} are pre-multiplied by the direct plus indirect land requirements matrix \mathbf{N} needed to make them. This derives a matrix of the amount of international land appropriated \mathbf{P} . Therefore:

$$\mathbf{P} = \mathbf{ON} \quad (6)$$

Secondly, land supporting domestic consumption \mathbf{R} is calculated by multiplying the international land appropriated \mathbf{P} by the fraction of final demand consumed locally $\hat{\mathbf{L}}$. Hence:

$$\mathbf{R} = \mathbf{P}\hat{\mathbf{L}} \quad (7)$$

Results for the study region are shown in Table 2.11. Summing the final column (or row) of Table 2.11 provides an estimate of the international land appropriated to support domestic consumption, δ (ie. 411,442 ha which represents 1.13 ha per capita).

Table 2.11 Land appropriated from other nations supporting domestic consumption for the hypothetical study region

	Agriculture	Manufacturing	Services	Domestic final demand	International totals
Agriculture	5,046	76,729	115,112	204,461	401,348
Manufacturing	9	179	322	564	1,074
Services	57	845	2,180	5,938	9,020
Sector totals	5,113	77,752	117,614	210,963	411,442

Note: All values are in ha per year.

2.3.6 Components of the ecological footprint and Ecological Balance of Trade

The ecological footprint is the sum total of purchases from intermediate demand sectors of the economy ($P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + \dots + P_n$) and from domestic final demand inputs ($D_1 + D_2 + D_3 + D_4$). The domestic final demand inputs consist of purchases of overseas imports (D_1) and purchases of regional imports (D_4) as well as the direct land occupied by the household dwellings (D_2) and its surrounding section, and the energy land required to absorb direct household CO₂ emissions (D_3). All of these inputs absorb can be tracked back to primary inputs of agricultural land, forest land, degraded land or energy land, using input–output analysis.

The Ecological Balance of Trade for a region is the exports ($R_1 + N_1$) minus the imports ($R_2 + N_2 + D_1 + D_4$). Again, these exports and imports can be tracked back to primary inputs of agricultural land, forest land, degraded land and energy land, using input–output analysis. This analytical framework is used to present the results in sections 4 to 19 of this report.

2.4 Data sources

Regional input–output matrices (16) are derived from the national input–output table produced by Statistics New Zealand using the GRIT methodology (1991, 1996, 1998, 1998a, 1999). Each input–output matrix covers 23 sectors. Estimates of land use data by economic sector are based on data gathered from Quotable Value New Zealand (1998), Statistics New Zealand (1998b, 1998c), Ministry of Agriculture and Forestry (1999), and Works Consultancy Services Ltd (1996). These estimates exclude national parks, inland water bodies (lakes and rivers) and marine land. Energy-related CO₂ emissions by economic sector were obtained from the Energy Efficiency and Conservation Authority (1997). The conversion of CO₂ emissions into energy land is based on sequestration data obtained from Hollinger et al (1993). They estimate that an average hectare of *Pinus radiata* in New Zealand absorbs 3.6 t of C per ha per year which equates to 0.0758 ha per t of CO₂ per year.¹⁴ Population statistics are based on sub-national estimates produced by Statistics New Zealand (1998d).

¹⁴ It is worth noting that these figures may vary considerably between regions depending on plantation age, soil type, climatic conditions and so on. The possibility of planting indigenous forest to sequester CO₂ emissions is also ignored (refer to Hall and Hollinger (1997) for further debate concerning this issue).

Figure 2.1 Components of the ecological footprint and Ecological Balance of Trade

