A three-perspective view of greenhouse gas emission responsibilities in New Zealand

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ABSTRACT

While responsibility for the environmental impacts of production has been commonly assigned to producers, production is driven by consumer demand, and it is valid to question whether impacts should instead be assigned to consumers. However, in each of these approaches producers and consumers either bear the full burden of responsibility or none at all. An example of this is the Kyoto Protocol, where all greenhouse gas emissions are assigned to the producer and no consideration is given to where goods are finally consumed. Rather than taking the conventional producer or consumer responsibility approach, a third perspective is possible in which responsibility is shared. We use input–output analysis to apply all three of these responsibility perspectives to New Zealand's domestic greenhouse gas emissions. Our main findings from the shared responsibility approach are that New Zealand producers are responsible for 44% of domestic emissions, New Zealand consumers take 28%, and 27% are exported. A shared responsibility approach appears to distribute the burden of responsibility and associated liability between parties more fairly, and is likely to be more widely acceptable than pure producer or consumer perspectives.

Keywords: Producer responsibility, consumer responsibility, shared responsibility, contribution analysis, input-output analysis

INTRODUCTION

The producer-centric approach is the accepted norm when discussing and accounting for environmental pressures from domestic agricultural and industrial production. Lenzen et al. (2007, p. 27) suggest this is "because of the tendency of economic policy in market-driven economies not to interfere with consumers' preferences". At an international level, this also applies with governmental policy emphasising environmental pressures within a governed territory. This can be considered a form of producer-focus with environmental pressures arising from production in other nations often not considered by the importing nation (the consumer). This 'producer responsibility' perspective places none of the burden of responsibility for environmental pressures on the consumer (or importing nation). The new challenge of global warming, however, transcends territorial boundaries, highlighting one of the weaknesses of the producer responsibility approach.

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An alternative perspective is that consumers assume responsibility for environmental impacts associated with production (Bastianoni et al., 2004; Hamilton and Denniss, 2005; Lenzen et al., 2007). This philosophy has a long tradition, with Adam Smith as early as 1776 stating that "consumption is the sole end and purpose of all production" (quoted by Lenzen et al., 2006).

Consumption has been a long-neglected topic when it comes to environmental pressures (Cohen, 2001). Rapid growth in developing economies and the associated wealth accruing to millions of people has heightened awareness of consumption as an influential force in striving for sustainability. Globalisation, with extensive overseas trade, makes consumption an international rather than national issue as purchases by residents in importing countries deplete resources in, and put environmental pressures on, the exporting countries.

Action to reduce global warming reinforces the international nature of production and consumption. Attempts to hold countries accountable for their CO_2 emissions have given rise to concern about who is responsible for the significant amount of CO_2 embodied in goods traded internationally (Munksgaard and Pedersen, 2001; Bastianoni et al., 2004). Should the producing country have to bear the cost or is the country where the goods are consumed ultimately responsible? This is an important policy question when one considers expanding economies, such as that of China, that export large volumes of goods. Figures like annual CO_2 emitted per unit of GDP or per capita can be misleading when applied to open economies with large net imports or exports of CO_2-intensive goods. This suggests the need to expand the accounting of CO_2 emissions to include CO_2 embodied in internationally traded non-energy goods. As world population grows and income levels rise, more emphasis is being placed on consumption patterns in environmental discourse.

However, the consumer responsibility perspective is not the silver-bullet solution to this dilemma, and both the producer and consumer responsibility perspectives have distinct advantages and disadvantages. The key advantage of the producer responsibility approach is that calculation is straightforward because the necessary data is already available. Under the Kyoto Protocol, for example, nations are required to create a detailed inventory of their domestic greenhouse gas emissions, and these inventories are all that is required to determine liability under the Protocol[2]. No knowledge is required of imports or other nations' activities. However, the producer responsibility perspective has a clear disadvantage for nations with significant environmental impacts associated with the production of exported goods, and conversely a clear advantage for nations that import those goods. The scope is also greater for 'carbon leakage' and 'pollution havens' (see, e.g., Peters and Hertwich, *in press*).

On the other hand, while the consumer responsibility perspective requires significantly more data and more sophisticated methods to calculate accurately, this alternative approach would clearly be preferred by nations exporting emissions-laden exports.

If domestic (or international) negotiations centre on whether to assign responsibility for environmental pressures completely to either producers (exporting nations) or consumers (importing nations), it is difficult to see both sides accepting the outcome. Given this potential for a stalemate situation, consideration of a third perspective is required, and one such perspective is presented by the work of Lenzen et al. (2007), which introduces a mathematical formulation for 'shared responsibility.' This perspective shares responsibility for environmental impacts associated with production based on the benefit obtained by each actor in the supply chain through to the consumer, using value-added as a proxy. From a national perspective, these benefits include employment, earning foreign exchange, and tax revenues. Benefits to consumers include cheaper goods, more choice, and better technology.

These issues are particularly relevant to New Zealand, where the economy for the last 150 years has been founded on the production and processing of primary products (see, e.g.,

[2] Except for a small number of special exemptions, including Denmark's electricity trade.

Cross, 1990; Ballingall and Lattimore, 2004). Exports of primary products between 1985 and 2005, consistently contributed more than 45% of New Zealand's total export earnings (Ballingall and Lattimore, 2004; Statistics New Zealand, 2006). Indeed, the vast majority of New Zealand's agricultural production is destined for export markets, with over 90% of meat and dairy production, more than 85% of wool, and high proportions of the many wood products exported. Set against this, emissions of greenhouse gases from the agriculture sector alone contributed 48.5% of New Zealand's total emissions for 2005 (Ministry for the Environment, 2007). In contrast, emissions from agriculture typically make up 12% of total greenhouse gas emissions in other Annex 1 Parties (Ministry for the Environment, 2007). Clearly the stakes are high for New Zealand as to whether a producer or consumer responsibility approach is used in international (e.g., post-Kyoto, trade) negotiations.

In this paper we apply all three perspectives to New Zealand's greenhouse gas emissions using the Leontief input–output model for 48 sectors in the year ended March 2001. Many international studies report only carbon dioxide emissions. However, because of New Zealand's high dependence on primary production, methane and nitrous oxide combined contribute more to total greenhouse gas emissions than does carbon dioxide (Ministry for the Environment, 2006, p. 184), and sequestration by forestry is a significant part of the greenhouse gas inventory. We therefore combine emissions of carbon dioxide, methane, and nitrous oxide with sequestration to give figures for GWP, expressed in units[3] of Tg CO_2-eq.

METHODOLOGY

There is a wide variety of techniques available for evaluating environmental impacts. For a recent, succinct summary of methods, see Finnveden and Moberg (2005).

For this study we have chosen to use extended input–output analysis because of data availability, the flexibility of the method to allow exploration of sectoral supply chains, and the method's comprehensive coverage.

Input–output tables – developed by Wassily Leontief during the 1930s and 1940s – provide a comprehensive snapshot of the structure of inter-industry linkages in an economy (Leontief, 1986). The Leontief Inverse matrix, derived from the input–output table, captures the infinite regression of transactions between industries of the economy, thereby uncovering the indirect economic requirements of each industry. These indirect requirements can be extended to environmental pressures, and authors such as Daly (1968), Isard et al. (1968), Ayres and Kneese (1969), Leontief (1970), and Victor (1972) were among the first to demonstrate that biophysical information on resource use and waste generation may also be considered in an input–output framework. For recent examples of the application of input–output analysis to environmental impacts see Lenzen (2001; 2003), Munksgaard et al. (2005), Wiedmann et al. (2006), Giljum and Hubacek (2001), Hubacek and Giljum (2003), and Wood and Lenzen (2003). For succinct reviews of the methodology, see, for example, Duchin and Steenge (1999) and Forssell and Polenske (1998).

Input–output analysis relies on several significant assumptions, the most important of which is homogeneity, i.e. each industry produces a single product and all output uses the same process and technology and therefore each of an industry's outputs has the same environmental impact per dollar. Bicknell et al. (1998) and Lenzen (2001) investigate the

[3] Tg CO_2-eq is an abbreviation of Teragrams of carbon dioxide equivalent, where 1 Tg = 10^{12} g = 1 million tonnes. Carbon dioxide equivalent (CO_2-eq) is a measure of the equivalent amount of carbon dioxide that would result in the same global warming potential as the emitted gases. We have followed the UNFCCC reporting requirements in using the 100-year global warming potentials listed in the IPCC Second Assessment Report (Houghton et al., 1995).

significance of this assumption in detail, along with various other assumptions. Most of these other assumptions are or concern only in forecasting analyses, whereas this study is a static snapshot analysis.

The following sections describe in detail: (i) the standard methodology from both the final demand and industry perspectives, (ii) ultimate contribution analysis, (iii) correct summation of a group of industries, (iv) reassignment of electricity emissions, and (v) the shared responsibility approach.

Standard Methodology

The flows in an economy can be modelled using an input–output table, which is composed of four main submatrices, as depicted in Figure 1. Let **S** be this full matrix.

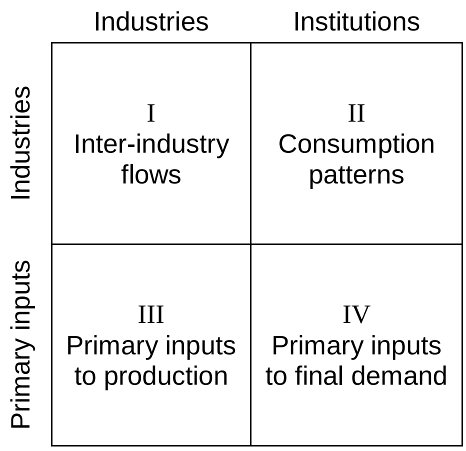

Figure 1: Basic structure of an input–output matrix

The inter-industry matrix (Quadrant I; upper-left of Figure 1) is a compact summary of the transactions between productive sectors (industries) of the economy. Let $\mathbf{S_I}$ be this $n \times n$ matrix, such that each element of $\mathbf{S_I}$ gives the purchases by one industry from another, and n is the number of industries. There are two distinct perspectives of calculation – final demand and industry. We will first deal with the more common final demand perspective.

The Final Demand Perspective

We first calculate the industrial output vector, **x**, as the sums of the rows of the social accounting matrix:

$$\mathbf{x} = \left[\mathbf{S_I} \mid \mathbf{S_{II}}\right]\mathbf{1} \tag{1}$$

where **1** is a column vector of ones, so that the elements of **x** are the sums of the rows of quadrants I and II of **S**.

Then the *technical coefficients* matrix, **A**, can be defined by:

$$\mathbf{S_I} = \mathbf{A}\hat{\mathbf{x}} \tag{2}$$

Such that[4]:

$$\mathbf{A} = \mathbf{S_I}\hat{\mathbf{x}}^{-1} \tag{3}$$

[4] Note that $\hat{\mathbf{x}}^{-1}$ is the inverse of the diagonal matrix formed from **x**, and post-multiplication by the inverse diagonal matrix is equivalent to dividing each column by the elements of **x**.

From the technical coefficients matrix, **A**, the *Leontief Inverse* matrix, **L**, is formed as:

$$\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1} \tag{4}$$

where **I** is the $n \times n$ identity matrix. The elements of the Leontief Inverse matrix (Leontief coefficients) represent the total direct and indirect requirements of any industry j (in columns) supplied by other industries i within the region in order for industry j to be able to deliver $1m worth of output to final demand.

Direct environmental pressures are given by the physical sectoral inputs or outputs in the resource accounts. First, we define the environmental pressure matrix as:

$$\mathbf{Q} = \left[\mathbf{Q}_{Ind} \mid \mathbf{Q}_{FD}\right] \tag{5}$$

By definition, direct environmental intensities[5] are calculated by dividing each industry's direct environmental pressure by its economic output:

$$\mathbf{M}_{\mathbf{D}} = \mathbf{Q}_{Ind}\hat{\mathbf{x}}^{-1} \tag{6}$$

where $\mathbf{M}_{\mathbf{D}}$ is the $m \times n$ matrix of direct environmental intensities, m being the number of pressures under investigation, and $\mathbf{Q}_{Ind}$ is the $m \times n$ matrix of direct environmental pressures (rows) by industry (columns).

The matrix of total (i.e. direct plus indirect) environmental intensities, $\mathbf{M}_{\mathbf{T}}$, is calculated as the product of the matrix of direct environmental intensities, $\mathbf{M}_{\mathbf{D}}$, and the Leontief Inverse, **L**:

$$\mathbf{M}_{\mathbf{T}} = \mathbf{M}_{\mathbf{D}}\mathbf{L} \tag{7}$$

The *indirect* environmental pressures resulting from final demand expenditure are now calculated by multiplying the total industry environmental intensities, $\mathbf{M}_{\mathbf{T}}$, by the final demand purchases from industry, **Y**:

$$\mathbf{U}_{\mathbf{T},FD} = \mathbf{M}_{\mathbf{T}}\mathbf{Y} \tag{8}$$

The sum of the indirect pressures due to purchases by final demand and direct pressures caused by final demand[6] is equal to the national total for each pressure:

$$\mathbf{Q1} = \left(\mathbf{U}_{\mathbf{T},FD} + \mathbf{Q}_{FD}\right)\mathbf{1} \tag{9}$$

The final demand institutional accounts are households, government, savings and investment, and rest of world (exports). Some investigators first report appropriations associated with exports and then declare the remainder to be domestic. However, while a significant proportion of government final demand is on behalf of households, it is difficult to determine this proportion and divide government expenditure to the appropriate economic beneficiary. Furthermore, savings and investment is a function of expected future rather than present output, and is also partly made in expectation of future domestic demand and partly for future export demand. Because of these difficulties, we do not assign government expenditure or savings and investment to either households or exports, but report them as a separate, combined category: Other final demand (shortened to "Other FD" in the tables).

[5] We use the terminology of Huppes and Ishikawa (2005), who define *environmental intensity* as environmental impact per unit of production value.

[6] The only final demand account that directly exerts pressures on the New Zealand environment is the households sector. The remaining final demand accounts only represent transfers of money (government and savings and investment), or activities outside New Zealand (exports).

The Industry Perspective

So far we have discussed calculations from the final demand perspective. When reporting at an industry level, it is important to prevent double counting by removing first-order intrasectoral transactions. This is done by setting the main diagonal of the transaction matrix to all zeros. If this was not done, ecological effects counted as direct for an industry would also be counted as indirect for the same industry.

$$\mathbf{S}_{\mathbf{I}}^{\circ} = \mathbf{S}_{\mathbf{I}} - diag(\mathbf{S}_{\mathbf{I}}) \tag{10}$$

Because of this modification, when reporting for individual industries the industrial economic output used is net of first-order intra-sectoral transactions (i.e. an industry's purchases from itself, which are the elements on the main diagonal of **G**). Let **z** be this $n\times 1$ vector. The steps represented by equations (1) through (7) are then repeated here, except that $\mathbf{S}^{\circ}$ and **z** are used as starting points in place of **S** and **x**, respectively:

$$\mathbf{z} = \left[\mathbf{S}_{\mathbf{I}}^{\circ} \,\vdots\, \mathbf{S}_{\mathbf{II}}\right]\mathbf{1} \tag{11}$$

$$\mathbf{S}_{\mathbf{I}}^{\circ} = \mathbf{A}^{\circ}\hat{\mathbf{z}} \tag{12}$$

$$\mathbf{A}^{\circ} = \mathbf{S}_{\mathbf{I}}^{\circ}\hat{\mathbf{z}}^{-1} \tag{13}$$

$$\mathbf{L}^{\circ} = \left(\mathbf{I} - \mathbf{A}^{\circ}\right)^{-1} \tag{14}$$

$$\mathbf{M}_{\mathbf{D}}^{\circ} = \mathbf{Q}_{Ind}\hat{\mathbf{z}}^{-1} \tag{15}$$

$$\mathbf{M}_{\mathbf{T}}^{\circ} = \mathbf{M}_{\mathbf{D}}^{\circ}\mathbf{L}^{\circ} \tag{16}$$

Now, the total environmental intensities are equal to the sum of direct and indirect intensities:

$$\mathbf{M}_{\mathbf{T}}^{\circ} = \mathbf{M}_{\mathbf{D}}^{\circ} + \mathbf{M}_{\mathbf{I}}^{\circ} \tag{17}$$

Therefore, the matrix of indirect environmental intensities, $\mathbf{M}_{\mathbf{I}}^{\circ}$, is calculated by subtracting the direct environmental intensities, $\mathbf{M}_{\mathbf{D}}^{\circ}$, from the total environmental intensities, $\mathbf{M}_{\mathbf{T}}^{\circ}$:

$$\mathbf{M}_{\mathbf{I}}^{\circ} = \mathbf{M}_{\mathbf{T}}^{\circ} - \mathbf{M}_{\mathbf{D}}^{\circ} \tag{18}$$

Total environmental pressure appropriations (in physical units) are then calculated by multiplying each industry's total environmental intensity by its economic output:

$$\mathbf{U}_{\mathbf{T}} = \mathbf{M}_{\mathbf{T}}^{\circ}\hat{\mathbf{z}} \tag{19}$$

Ultimate Contribution

The *Ultimate Contribution* identifies which sectors ultimately created the pressure on the environment. This helps answer the question: "Which sectors were the major resource users or pollutant generators that made a significant contribution to how much a sector appropriated?"

To calculate ultimate sectoral contributions to environmental pressure appropriation by an industry, the same operations are performed as outlined in the main method (Equations 7 and 19), but without the summing action of matrix multiplication. This can be summarised for all industries as:

$$\mathbf{C}_{ult}^{k} = \hat{\mathbf{f}}_{\mathbf{D}}^{k}\mathbf{L}\hat{\mathbf{z}} \tag{20}$$

where $\mathbf{C}_{ult}^{k}$ is an $n \times n$ matrix indicating ultimate contribution to environmental pressure (pressure k) appropriation of industries (in columns) by industries (in rows); $\hat{\mathbf{f}}_{\mathbf{D}}^{k}$ is the $n \times n$ diagonal matrix formed from the vector of direct environmental intensities for resource k (i.e. $\mathbf{f}_{\mathbf{D}}^{k}$ is the kth row of $\mathbf{M}_{\mathbf{D}}$); $\mathbf{L}$ is the $n \times n$ Leontief Inverse matrix; and $\hat{\mathbf{z}}$ is the $n \times n$ diagonal matrix formed from the vector of industrial economic output net of first-order intrasectoral transactions ($\mathbf{z}$).

Note that the total environmental pressure appropriation by sector for resource k, $\mathbf{U}_{\mathbf{T}}^{k}$, can be recreated from $\mathbf{C}_{ult}^{k}$ by summing the ultimate sectoral contributions:

$$\mathbf{U}_{\mathbf{T}}^{k} = \mathbf{1}\mathbf{C}_{ult}^{k} \tag{21}$$

where $\mathbf{1}$ is a $1 \times n$ vector of ones.

Similarly, the ultimate contributions to appropriation of environmental pressures by final demand categories can be calculated as follows:

$$\mathbf{C}_{ult,FD}^{k} = \hat{\mathbf{f}}_{\mathbf{D}}^{k}\mathbf{L}\mathbf{Y} \tag{22}$$

where $\mathbf{Y}$ is the matrix of final demand purchases (quadrant II in Figure 1), and $\mathbf{C}_{ult,FD}^{k}$ is an $n \times p$ matrix indicating ultimate contribution to environmental pressure (pressure k) appropriation of final demand institutional accounts (in columns) by industries (in rows).[7]

Summing industrial appropriations

To compare the total appropriations of GWP by a group of industries to New Zealand totals, it is necessary to remove any double counting that would occur if the direct and indirect figures calculated for each industry were simply added[8]. For example, adding the dairy processing total to the dairy farming total would count the impacts of the dairy farming industry twice (once as direct for farming, a second time as indirect for processing). To remove these double-counts, all forward linkages from the group of industries must be removed by setting the corresponding rows of the coefficient matrix to zeroes.

Mathematically:

$$\mathbf{A}^{*} = \hat{\mathbf{e}}_{i}\mathbf{A}^{\circ} \tag{23}$$

where, letting s be a set of the group of industries under investigation,

$$\mathbf{e}_{i} = \begin{cases} 1 & if\ i \notin s \\ 0 & if\ i \in s \end{cases} \tag{24}$$

This leaves direct environmental pressures unchanged, but can have a large impact on the indirect appropriations because any indirect appropriations from industries within the group have been removed. Using the same example, the indirect GWP appropriation calculated for the dairy processing industry using this method no longer includes the methane emissions from the farming industries. The resulting 'indirect' appropriations are termed 'adjusted indirect appropriations' in this paper. Note this method is *only* suitable when summing a group of industries.

[7] Note that equation (22) is a generalisation of the model presented as equation (2) of Munksgaard and Pedersen (2001).

[8] Note this refers to a form of double counting not covered by equation (10).

Electricity generation adjustments

The environmental accounts matrix, **Q**, assigns electricity generation emissions to the using sector. However, when analysing final demand appropriations from industry it would be preferable to have emissions associated with electricity generation indicated as such. It is not possible simply to assign them in the environmental accounts matrix to the electricity generation industry because supply of energy to using sectors is grossly out of proportion with the monetary flows.

Rather than introduce a hybrid-unit model[9] we take a simpler approach in which we reassign emissions due to generation of electricity back to the electricity generation sector while ensuring that appropriations downstream to final demand sectors remains untouched.

By augmenting the environmental accounts matrix with electricity consumption in physical units, we can track appropriations of electricity use through the economy to final demand along with primary environmental pressures. Knowing then how much electricity consumption is appropriated by each final demand category, we can reassign these back to the electricity generation sector, and then convert this to a GWP[10]. Effectively we relabel the ultimate sources of electricity *consumption* by industry as electricity *generation*, all from the single electricity generation industry. We represent this as:

$$\mathbf{C}_{ult,ij}^{GWP}\Big|_{i=elecgen} \mathrel{+}= \sum_{i} \mathbf{C}_{ult,ij}^{elecCO_2} \tag{25}$$

where the += operator indicates addition of the quantity on the RHS of the equation to the existing quantity on the LHS. We must also ensure that the GWP appropriated from every other sector excludes the GWP associated with electricity generation, by tracking all types of emission and sequestration separately.

Shared responsibilities

Lenzen et al. (2007) introduced a solution to the problem of producer versus consumer responsibility with a formulation that is invariant with respect to the aggregation level of the input–output table. They use value-added as the proportion of responsibility that is 'held' by each industry, the remaining responsibility being 'passed on' to downstream industries or final demand. For full details of this approach, we refer the reader to the work of Lenzen et al. (2007).

We implement this approach here, using the notation introduced above. However, we have achieved the same result with a different formulation of the equations. First we take the transaction matrix with the main diagonal set to zeros, $\mathbf{S}^{\circ}$, and zero quadrants III and IV, to prevent circular (income distribution) effects when we invert:

$$\mathbf{S}_{ij}^{\circ\circ} = \begin{cases} \mathbf{S}_{ij}^{\circ} & if\ i \in v \\ \mathbf{0} & if\ i \notin v \end{cases} \tag{26}$$

where v is the set of industries such that only the industry rows of the matrix remain intact[11].

Then we calculate a modified Inverse Leontief matrix, adjusting transfers according to the proportion of value-added:

[9] For details of such an approach, see, for example, Dietzenbacher and Stage (2006)

[10] Note that electricity emission factors are calculated for end-use (consumer) electricity, which means that distribution losses are included.

[11] This could also be seen simply as adjoining quadrants I and II and then padding the matrix such that it is square.

$$\mathbf{L}^{\mathbf{r}} = \left(\mathbf{I} - \hat{\boldsymbol{\alpha}}\hat{\mathbf{z}}^{-1}\mathbf{S}^{\circ\circ}\right)^{-1} \tag{27}$$

where $\boldsymbol{\alpha}$ is a vector of value-added proportions, and $\mathbf{z}$ is defined in Equation 11, above.

Last, we calculate the responsibilities for each environmental pressure by post-multiplying the environmental accounts matrix by the modified Inverse Leontief and the passed-on share, represented by $\left(\mathbf{I} - \hat{\boldsymbol{\alpha}}\right)$:

$$\mathbf{R} = \mathbf{Q}\mathbf{L}^{\mathbf{r}}\left(\mathbf{I} - \hat{\boldsymbol{\alpha}}\right) \tag{28}$$

where $\mathbf{R}$ is a matrix of responsibilities for pressures (in rows) by sectors (in columns, both industry and final demand). Note that it is not necessary in this formulation to calculate environmental intensities, $\mathbf{M_D}$.

DATA COLLECTION AND PREPARATION

All data and analyses were for the year ended March 2001 at a national level for New Zealand. All base data were collected for 48 industries of the economy[12]. A New Zealand Monetary Input-output Table (MIOT) for 2001 was constructed (MEL, 2004) by updating the most recently available MIOT (year ended March 1996) provided by the national statistics agency (Statistics New Zealand, 2001). This update procedure used the producers' price index to update to 2001 prices, labour productivity and employment data to update sector outputs, various official 'superior' data as available for some cells and totals, final demand and primary inputs from Statistics NZ, and finally RAS optimisation on the transaction matrix to balance the table.

Resource accounts for the 48 industries were created from a range of sources. Greenhouse gas emissions were derived from New Zealand's official National Inventory Report (Ministry for the Environment, 2006) along with data obtained directly from the Ministry (Sonia Petrie, MfE, pers. comm.). Energy-use data, used to disaggregate energy CO_2 emissions by industry, were taken from a variety of sources including Jollands (2003), Ministry of Economic Development (2004), and the Energy Efficiency and Conservation Authority (2004). Sequestration was divided between the farming industries and the forestry industry according to estimated afforestation rates. The New Zealand net sequestration total for year ended March 2001 from the Land Use, Land Use Change, and Forestry (LULUCF) category of the UNFCCC[13] reporting process was approximately −21.3 Tg CO_2-eq, or 30% of total emissions[14].

Because most of the data used in this study are estimated and provided with no useful certainty bounds, uncertainty analysis is impossible. In particular, the method used to update the input–output table to 2001 initially assumes technical coefficients remain constant over time, and then adjusts for inconsistencies using RAS balancing. The resulting errors are difficult, if not impossible to quantify. Similarly, assumptions have been made to disaggregate national estimates of environmental pressures to sectors. Data collection is ongoing, including detailed and comprehensive collection by research partners liaising with industry. In addition, New Zealand's official statistics department states that new official supply and use tables (from which an input–output table can be derived) are to be released in

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[12] A concordance with the ANZSIC classification is available from the authors on request.
[13] United Nations Framework Convention on Climate Change
[14] Estimated from calendar-year data; this figure is for Kyoto afforestation, i.e. afforested land not forested in 1990

2008 (Statistics NZ, pers. comm.). As a consequence, the results presented here may change as better data become available.

Importantly, imports have not been included in this work. Data were not readily available at the time of research. We discuss the implications of this exclusion in the Discussion section.

RESULTS

This section outlines the results from analysing the New Zealand economy from three perspectives. The first is the producer perspective, where we focus on the agriculture and forestry value chain[15]. This is because agricultural sectors are responsible for approximately 50% of New Zealand's GWP. The second is the consumer perspective, where we look at the appropriations by New Zealand households and by exports. The third perspective is that of responsibility shared between producers and consumers.

Industry appropriations

The appropriations of global warming potential (GWP) by eight industries that cover the majority of the agriculture and forestry value chain are presented in Tables 1a, 1b, and 1c. These show a mix of positive values (representing net emissions) and negative values (representing net sequestration). Direct summations include both emissions of greenhouse gases and sequestration from any associated forestry activities.

As expected, there is a clear distinction between the primary industries, which have high-magnitude direct GWPs (positive for agriculture and negative for forestry), and the associated processing industries, which have high-magnitude indirect GWPs (positive for meat, dairy, and textile processing, and negative for wood processing), mostly inherited from their respective primary industries. The exception to this rule is the paper industry, which used more natural gas than any other industry in the economy[16]. Given the very high total energy use by the paper industry, it might be expected that its GWP would be even higher than it is. However, 69% of its direct energy was from renewable (black liquor and wood waste) or low-emission (geothermal) sources.

Each of agriculture and forestry industries appropriated GWP indirectly from a common set of industries including road transport, chemical and metal manufacturing, and services to agriculture. In most cases, industries outside the agriculture and forestry value chain contributed little to the total GWP of those within the group.

The livestock and cropping farming industry had the highest direct (18.93 Tg CO_2-eq) and total GWP (19.41 Tg CO_2-eq), representing 3.4 Tg per billion dollars (NZ) of output[17]. The direct GWP of the dairy farming industry was also high at 12.07 Tg CO_2-eq and a total of 12.8 Tg CO_2-eq, representing 2.6 Tg/$NZbillion of output. While dairy cattle have higher methane emissions per head, because of the large number of sheep and beef farmed in New Zealand, the livestock and cropping farming industry's GWP was higher. Both these industries had net-positive Kyoto afforestation in 2001, and the sequestration from that planting has resulted in a lower direct GWP than might otherwise have been. In addition, both livestock and cropping farming and dairy farming appropriated sequestration from the forestry industry through the purchase of wood products.

[15] The Textile and Apparel manufacturing sector is included because it uses large volumes of wool, skins and hides sourced from livestock and dairy farming

[16] Discounting electricity generation

[17] Estimates of GWP per dollar output have been calculated using data from the input–output table

The forestry and logging industry made the largest contribution to offsetting New Zealand's greenhouse gas emissions, with a direct total GWP of −14.03 Tg CO_2-eq. This figure includes the warming potential associated with energy use by the industry. In comparison, the industry's appropriation of indirect GWP from other industries is relatively small, reducing the net sequestration by only 4%.

Table 1a: Direct and largest ultimate contributions to indirect appropriation of global warming potential by the livestock and cropping farming, dairy farming, and forestry and logging industries

Livestock and cropping farming	Tg CO_2-eq	Dairy cattle farming	Tg CO_2-eq	Forestry and logging	Tg CO_2-eq
Direct	18.93	Direct	12.07	Direct	-14.03
Forestry	-0.22	Livestock and Crops	0.67	Road Transport	0.27
Other Farming	-0.22	Forestry	-0.20	Livestock and Crops	0.12
Dairy Farming	0.20	Other Farming	-0.17	Services to Ag	0.05
Road Transport	0.13	Road Transport	0.08	Petroleum	0.02
Services to Ag	0.12	Petroleum	0.06	Basic Metals	0.02
Petroleum	0.05	Services to Ag	0.06	Other Farming	-0.01
Others	0.40	*Others*	0.27	*Others*	0.03
Total	19.41	Total	12.84	Total	-13.53

Table 1b: Direct and largest ultimate contributions to indirect appropriation of global warming potential by the meat processing and dairy processing industries

Meat and meat product manufacturing	Tg CO_2-eq	Dairy product manufacturing	Tg CO_2-eq
Direct	0.41	Direct	0.91
Livestock and Crops	12.04	Dairy Farming	11.26
Other Farming	-1.02	Livestock and Crops	1.48
Road Transport	0.48	Other Farming	-0.31
Dairy Farming	0.44	Forestry	-0.26
Forestry	-0.33	Road Transport	0.21
Services to Ag	0.14	Basic Metals	0.08
Others	0.47	*Others*	0.57
Total	12.63	Total	13.95

Table 1c: Direct and largest ultimate contributions to indirect appropriation of global warming potential by the textile and apparel manufacturing, wood processing, and paper manufacturing industries.

Textile and apparel manufacturing	Tg CO_2-eq	Wood product manufacturing	Tg CO_2-eq	Paper and paper product manufacturing	Tg CO_2-eq
Direct	0.16	Direct	0.20	Direct	0.79
Livestock and Crops	1.76	Forestry	-4.78	Forestry	-0.45
Forestry	-0.12	Road Transport	0.20	Road Transport	0.08
Road Transport	0.12	Livestock and Crops	0.09	Livestock and Crops	0.03
Other Farming	-0.10	Basic Metals	0.04	Basic Metals	0.02
Dairy Farming	0.07	Dairy Farming	0.03	Dairy Farming	0.01
Basic Metals	0.04	Petroleum	0.03	Petroleum	0.01
Others	0.19	*Others*	0.13	*Others*	0.06
Total	2.11	Total	-4.06	Total	0.55

Total appropriation by a functionally related group of industries

By removing forward linkages, we can calculate the total appropriation by a functionally related group of industries. Table 2 shows that the agriculture and forestry value chains were directly responsible for 19.44 Tg CO_2-eq of global warming potential. These industries also appropriated an additional 1.61 Tg CO_2-eq from other industries, giving a total of 21.04 Tg CO_2-eq, which represents about 47% of the total GWP for New Zealand in 2001.

Table 2: Direct, adjusted indirect*, and total 2001 global warming potential appropriation (Tg CO_2-eq) by the agriculture and forestry value chain

Industry	Direct	Indirect*	Total
Livestock and cropping farming	18.93	0.29	19.22
Dairy cattle farming	12.07	0.23	12.30
Forestry and logging	-14.03	0.40	-13.63
Meat and meat product manufacturing	0.41	-0.16	0.25
Dairy product manufacturing	0.91	0.28	1.19
Textile and apparel manufacturing	0.16	0.18	0.34
Wood product manufacturing	0.20	0.24	0.43
Paper and paper product manufacturing	0.79	0.14	0.93
Total	19.44	1.61	21.04

* Adjusted indirect appropriation, not including appropriations from the agriculture and forestry value chain

Total Appropriation of Final Demand: The Consumer Perspective

Because all economic activity is undertaken for final demand (FD), all environmental pressures associated with environmental activity can be assigned to final demand based on purchases. However, it is unreasonable to assume that the final demand category *Savings and Investment*, which includes capital formation, is a purely domestic activity. Much capital investment is made in the expectation of future export demands, particularly in an export-oriented economy such as New Zealand's. It is therefore difficult to separate domestic and exported appropriations for the final demand category *Savings and Investment*. In this section we report the households and exports (rest of world) categories of final demand, and group the government and savings and investment categories together (Other FD).

The direct and ultimate contributions for each of the final demand categories are summarised in Table 3, highlighting larger contributions from specific industries. The figures reveal that exports appropriated about twice as much GWP from New Zealand industry as New Zealand households (23.05 Tg CO_2-eq vs 12.43 Tg CO_2-eq). However, households were directly responsible for 6.88 Tg CO_2-eq of additional GWP from their own use (home heating, domestic transport, etc.). The other final demand categories (Other FD) appropriated a significant proportion of the net sequestration from the forestry industry because afforestation and the growth of standing forest are regarded as a change in inventories.

Table 3: Appropriations of New Zealand's 2001 global warming potential by New Zealand households, exports, and other final demand categories

Source	Households (Tg CO2-eq)	Exports (Tg CO2-eq)	Other FD (Tg CO2-eq)
Primary	4.80	13.41	-1.73
Livestock and Crops	*4.85*	*13.21*	*0.85*
Dairy Farming	*1.75*	*9.18*	*1.06*
Forestry	*-1.68*	*-8.61*	*-3.77*
Other Primary	*-0.12*	*-0.38*	*0.13*
Manufacturing	1.49	5.03	1.44
Basic Metals	*0.37*	*2.76*	*0.33*
Other Manufacturing	*1.12*	*2.27*	*1.11*
Services	6.14	4.62	2.68
Electricity Generation	*2.72*	*1.70*	*0.63*
Road Transport	*1.17*	*1.47*	*0.58*
Other Services	*2.25*	*1.45*	*1.46*
Total from Industry	12.43	23.05	2.38
Direct	6.88		
Total	19.31 (43%)	23.05 (52%)	2.38 (5%)

Shared responsibilities

Responsibilities for GWP by industry and final demand derived using the approach of Lenzen et al. (2007), are shown in Table 4.

Table 4: Responsibilities for New Zealand's 2001 global warming potential under the shared responsibility formulation

Sector	GWP responsibility ($Tg\ CO_2$-eq)	
Primary	6.08	
Livestock and Crops		*7.05*
Dairy Farming		*5.99*
Other Farming		*-1.03*
Forestry		*-7.10*
Other Primary		*1.16*
Manufacturing	5.55	
Meat Processing		*1.81*
Dairy Processing		*0.76*
Textiles		*0.33*
Wood Processing		*-0.61*
Paper		*0.35*
Basic Metals		*1.02*
Other Manufacturing		*1.88*
Services	7.48	
Road Transport		*2.25*
Other Services		*5.22*
Final Demand	25.65	
Households		*12.93*
RoW		*11.81*
Other FD		*0.91*
Total	44.75	

This methodology for sharing responsibility assigns 57% of the responsibility for New Zealand's domestic GWP to final demand categories, split approximately equally between households (29%) and exports (26%), with a very small responsibility for other final demand (Other FD) categories (2%). Of the share apportioned to industry (43%), there was a fairly even split between the three major groups of industries – Primary, Manufacturing, and Services. The responsibility apportioned to primary sectors is substantially reduced by forestry sequestration.

Comparison

Table 5 demonstrates how the three perspectives compare, with the producer perspective assigning responsibility to direct emitters in proportion to their emissions and no burden of responsibility passed down the supply chain. Under this approach, New Zealand households are responsible for their direct emissions, primarily from energy consumption. However, because emissions are associated with domestic activity, the rest of world (RoW) category is assigned no responsibility under the producer perspective.

Table 5: Summaries of responsibilities for New Zealand's domestic greenhouse gas emissions using three perspectives: Producer responsibility, Consumer responsibility, and Shared responsibility

Sector	Producer	Consumer	Shared
Primary	37%	-	14%
Manufacturing	18%	-	12%
Services	30%	-	17%
NZ Households	15%	43%	29%
RoW	-	52%	26%
Other FD	-	5%	2%
Total	100%	100%	100%

In contrast, when the consumer perspective is used, the rest of the world is assigned (via exports) 52% of the responsibility for New Zealand's domestic emissions, compared with 43% for New Zealand households. This reflects the higher emissions intensity associated with New Zealand's export products. New Zealand households are still responsible for their own, direct emissions, and also accumulate responsibility for emissions through their purchases.

The shared responsibility approach assigns 74% of the responsibility for emissions to New Zealand. Interestingly, the distribution of responsibility between producers – aggregated here to major sectors of the economy – is significantly different under the shared responsibility approach compared to the producer approach. In particular, the responsibility assigned to the primary sectors is now lower than the service sectors. There are three important reasons for this: (i) the service sectors have accumulated more responsibility from upstream, (ii) because the service sectors have a higher value-added as a proportion of their total outputs[18], they pass on less accumulated responsibility, and (iii) the service sectors export much less than primary and manufacturing sectors so less responsibility is re-assigned to exports.

DISCUSSION

We have demonstrated the application of three perspectives on responsibility for one category of a nation's environmental impacts, namely greenhouse gas emissions. The three approaches are the producer, consumer, and shared responsibility perspectives.

We have applied our analysis to New Zealand's greenhouse gas emissions in the year 2001. Data collection is ongoing, and the results presented here may change with the acquisition of better data in the future. In particular, there is significant inter–annual variation in the sequestration by "Kyoto forestry" due to changing forest stocks and responses by the industry to market signals. With the recent announcement by the New Zealand Government of an emissions trading scheme, and optional devolution of credits and liabilities to forest owners, these market signals have been materially altered. However, the main argument of this paper is not based on the specific results obtained, but rather on the application of the methodology as a possible solution to the dilemma facing negotiators.

We acknowledge that this analysis is for New Zealand's domestic emissions and, critically, has excluded imports. Initial investigations using multi-regional input–output analysis techniques (see, e.g., Peters and Hertwich, 2006) and GTAP data indicate that *carbon dioxide* emissions (that is, excluding other greenhouse gases) embodied in New Zealand's imports are of a similar magnitude to those embodied in its exports (Glen Peters, pers. comm.). However, New Zealand's exports are likely to have significantly greater embodied emissions of *methane* and *nitrous oxide* than its imports, because of the large volumes of agricultural

[18] In 2001, the Primary sectors averaged 42%, Manufacturing 28%, and Services 52% (own calculations from the input–output table for 2001)

products exported. Total global warming potential embodied in New Zealand's exports is therefore likely to be significantly more than that embodied in its imports. Until globally harmonised sectoral non-CO_2 greenhouse gas data are available, the correct inclusion of emissions embodied New Zealand's imports can only be roughly estimated. Non-CO_2 greenhouse gas emissions data for use with the GTAP database are expected to be available soon (Thomas Hertel, pers. comm.).

There are several other sources of uncertainty in the methodology we have used that should be noted. While in reality industries produce a variety of outputs, input-output analysis assumes that each industry produces a homogeneous output. This leads to errors in appropriations of environmental impacts through the supply chain. However, the significance of the homogeneity assumption reduces with higher levels of sectoral disaggregation, and is unlikely to impose severe errors at the 48-sector level used in this study. Other uncertainties arise due to probable inaccuracies in the input-output table itself, both from its initial construction by the official statistics agency, and from the update process we have used. Collation of the environmental data and the process of allocation of these data to sectors also introduce uncertainty. Data improvement is already underway, with the imminent release of an updated input-output table, and on-going programmes within Statistics New Zealand, the official statistics agency, to improve environmental data sets.

New Zealand ratified the Kyoto Protocol in December 2002. While the target reduction for all Annex 1 parties (including New Zealand) to the Kyoto Protocol is 5% below 1990 GHG emission levels, New Zealand's current emissions are 24.7% higher (Ministry for the Environment, 2007). Emissions growth has been mainly driven by higher electricity and transport use, and increased agricultural production (Ministry for the Environment, 2007, p.18). Meeting current Kyoto commitments is likely to have some negative economic consequences, with the liability over the 2008–2012 period currently estimated at $704 million (The Treasury, 2007), or approximately 0.08% of annual GDP. Overall New Zealand produces 0.2% of global GHG emissions.

Efforts to reduce GHG emissions in New Zealand are hampered by high abatement costs. Currently about 69% of New Zealand's electricity is generated from renewable sources (Ministry of Economic Development, 2007), with the remainder generated from fossil fuels. While the New Zealand Government has recently announced a new target; that renewable sources should form 90% of electricity generation by 2025 (Clark, 2007), this is only likely to meet increased demand and therefore not reduce the need for existing thermal generation. Early this decade the Government negotiated agreements with heavy industry to move towards best international practice; scope for further efficiency improvement in the industrial sectors is therefore limited. Low overall population density often makes the use of public transport systems uneconomic outside the larger cities, and also results in high transport emissions from goods distribution. The very strong agricultural base of the economy provides the biggest challenge: in 2005 methane accounted for 35% of total emissions, and nitrous oxide contributed 17%, with most of these attributable to pastoral farming (Ministry for the Environment, 2007). Researchers have not yet found technologies to significantly reduce these emissions.

From a New Zealand perspective the producer-centric approach of the Kyoto Protocol is onerous. The agriculture and forestry industries are dominant in the greenhouse gas profile. Forestry sequestration allowed under the Kyoto Protocol offset almost a third of New Zealand's total greenhouse gas emissions in 2001. However, even with sequestration included, corrected summation of appropriations (i.e. preventing double counting) using the producer perspective shows agriculture and forestry value chains appropriated approximately 47% of the nation's net global warming potential in the year ended March 2001. Most of the output from the agriculture sectors is exported and consumed overseas but the GWP liability rests with NZ. Reducing emissions without reducing output and therefore export earnings is currently difficult.

An option for New Zealand – and other countries in a similar position – would be to advocate a consumer responsibility perspective in international negotiations. The consumption perspective presents an alternative that shifts responsibility for environmental pressures to consuming institutions, either New Zealand households or households in other nations via exports. This approach encourages further thinking about the extent of the consumers' responsibility for environmental impacts. Our results for 2001 show that a large proportion of the GWP generated in New Zealand is appropriated by overseas households via exports. Passing on the liability to the consumer has the potential to reduce New Zealand's emissions liability, but further analysis would be needed to confirm this. If such a policy resulted in higher prices on the international market for goods produced in New Zealand, consumers might well move away from New Zealand products which would impact negatively on the economy. Making consumers responsible for their GWP may also move production to countries not party to international agreements to limit GHG emissions, or to countries that produce goods in less environmentally sound ways than New Zealand does. This is contrary to the aim of the Kyoto Protocol, which is to reduce global GHG emissions. Another disadvantage of the consumer approach is that if the goods are exported to countries that are not party to international agreements to limit GHG emissions, responsibility for GHG emissions is not assumed by any nation and the motivation to reduce emissions is lost.

A third option is the shared responsibility formulation introduced by Lenzen et al. (2007). When applied to New Zealand, consumptive sectors are assigned just over half (56%) of responsibility for GWP, approximately equally split between New Zealand households and exports. Of the responsibility assigned to productive sectors, 32% was to primary industries, 29% to manufacturing, and 39% to services. This approach, while more complex, has the potential to be more politically acceptable. It acknowledges that the production of goods that generate GWP has advantages for the New Zealand economy (more employment, earning overseas exchange, higher tax takes) and reduces the disadvantages associated with transferring sole responsibility to the consumer. These include reducing demand for New Zealand exports, producing goods where the environmental impacts are greater, and passing on the full responsibility for GWP to countries that are not party to an international greenhouse gas emissions agreement.

There is a clear need to extend this research to estimate New Zealand's fiscal liability under a post-Kyoto scheme using each of the three perspectives. Such calculations must include rebound and other feedback mechanisms and would therefore require computable general equilibrium (CGE) models.

CONCLUSIONS

When quantifying environmental impacts a number of different approaches can be applied. This paper presents three perspectives, those of producer responsibility, consumer responsibility, and shared responsibility. All three perspectives are defensible, but whether one should be used in preference to the other depends on policy considerations.

Drafting policy and negotiating international agreements is a complex business fraught with pitfalls. It is difficult not to end up with perverse incentives that undermine the overall goal. The primary industries have formed the backbone of New Zealand's driven economy for 150 years, and their ecological and economic viability is important for the nation. Reducing GHG emissions from New Zealand agriculture is difficult and the overall goal of global emissions reductions is not achieved if the output from New Zealand drops and this market gap is filled by countries that produce goods with similar or greater levels of emissions. Similar issues will be faced by many countries that have ratified the Kyoto Protocol. Alternative approaches to allocating the liability for GHG emissions will therefore need to be found if negotiations for the post–Kyoto period are to succeed.

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