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Greenhouse gas emissions from the international maritime transport of New Zealand's imports and exports

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Abstract

Greenhouse gas emissions from international maritime transport are exempt from liabilities under the Kyoto Protocol. Research into quantifying these emissions is ongoing, and influences policy proposals to reduce emissions. This paper presents a cargo-based analysis of fuel consumption and greenhouse gas emissions from New Zealand's international maritime transport of goods. Maritime transport moves 99.5% (by mass) of New Zealand's internationally traded products. It is estimated that 73% of visiting vessels' activity can be directly attributed to the movement of goods in and out of New Zealand. A cargo-based methodology was used to estimate that the international maritime transport of New Zealand's imports and exports consumed 2.5 million tonnes (Mt) (2.6 billion litres) of fuel during the year 2007, which generated 7.7 Mt of carbon dioxide (CO_2) emissions. Double-counting of emissions would occur if a similar method was applied to all New Zealand's trading partners. In contrast, since few large vessels refuel in New Zealand, the National Greenhouse Gas Inventory listed 2007 international maritime transportation emissions as 0.98 Mt of CO_2, calculated from fuel bunkered for international transport. The results, therefore, show a significant difference between activity-based and bunker-fuel methodologies in quantifying New Zealand's emissions. International policy implications are discussed.

Keywords

International maritime transport; greenhouse gas emissions; New Zealand international trade

1. Introduction

The aim of this paper is to assess the methodologies for calculating greenhouse gas emissions from international maritime transport, and the policy implications of using these methodologies, through a case study of imports and exports to and from a single country, New Zealand. This case study will be useful for researchers and policy analysts seeking to carry out similar studies at national or regional levels, particularly if limited financial resources are available for purchasing access to commercial databases.

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Maritime vessels burn fossil fuels (mainly heavy fuel oil and marine diesel oil) for propulsive power and also to generate electricity for onboard needs. The main emissions by mass resulting from the combustion of these fossil fuels onboard are carbon dioxide (CO_2), sulphur dioxide (SO_2), and nitrogen oxides (NO_X) (the sum of NO and NO_2 emissions) and, in smaller amounts, carbon monoxide (CO), particulate matter (PM), non-methane volatile organic compounds (NMVOC), methane (CH_4), and nitrous oxide (N_2O) (Buhaug et al., 2009). CO_2, CH_4, and N_2O are three of the six types of Kyoto gases (gases which are included in reduction targets under the Kyoto Protocol) and are known greenhouse gases whose climate impacts are well documented (Solomon et al., 2007). The full effects and interactions of all emissions from shipping over short timescales, however, are not yet fully understood as both positive and negative radiative forcings are experienced from different emissions. Schreier et al. (2006) found that the mean surface radiation below a ship track was decreased by 43.25 W/m^2 due to the short-term cloud seeding effect of certain vessel emissions. Lauer et al. (2007) calculated a global annual average decrease in shortwave radiative flux at the top of the atmosphere of between 0.19 W/m^2 and 0.60 W/m^2 due to the indirect effects of shipping emissions. In the longer term, however, emissions from shipping will result in a warming response as the long-lasting effect of CO_2 will overwhelm any shorter-term cooling effects (Buhaug et al., 2009).

Studies that estimate emissions from the maritime industry often assert that the calculations have been made through either so-called “top-down” or “bottom-up” methods. Unfortunately, there is some inconsistency in how these terms are applied. For example, Corbett and Koehler (2003) used a methodology that would be classified as an activity-based bottom-up approach according to the nomenclature used in Buhaug et al. (2009), but would be classified as top-down according to Wang et al. (2007), Wang et al. (2008), and Eyring et al. (2010). Regardless of how they are termed, studies based on bunker fuel statistics, are, generally, simpler to undertake and involve calculating emissions based on the chemical composition of fuels which have been bunkered, and subsequently consumed, by maritime vessels. Another approach is to use activity-based calculations, which for ships involves calculating the amount of fuel consumed, and the resulting emissions, based on the activity of vessels. Activity-based studies sometimes risk double-counting; for example, if the full journeys for all exports and imports for two individual countries that trade only with each other were quantified, the total fuel use attributed to both countries would be twice the total actual fuel use. Comparisons of activity-based and bunker-fuel figures therefore need to be made with great care.

The Intergovernmental Panel on Climate Change (IPCC) National Greenhouse Gas Inventories Programme, at the invitation of the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the United Nations Framework Convention on Climate Change (UNFCCC), provides guidelines to assist countries to compile national inventories of greenhouse gases. The guidelines require the fuel use to be accounted for in National Greenhouse Gas Inventories. The IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (2.4 Mobile Combustion: Water-borne Navigation, 2.4.1.5 Choice of Activity Data) states:

> *“Fuel use data may be obtained using several approaches…likely sources of actual fuel or proxy data are listed below, in order of typically decreasing reliability:*
>
> • *National energy statistics from energy or statistical agencies;…*

- *Surveys of fuel suppliers (e.g. quantity of marine fuels delivered to port facilities);…*
- *Import/export records;*
- *Ship movement data and standard passenger and freight ferry schedules;*
- *Passenger counts and cargo tonnage data…"* (Eggleston et al., 2006)

Corbett and Koehler (2003) estimated that all international maritime journeys (including military journeys) consumed 289 Mt of fuel in the year 2001. Eyring et al. (2005) estimated that 280 Mt of fuel was consumed by all non-military international shipping during the year 2001. Contrary to these results, Endresen et al. (2003) calculated that 144 Mt of fuel was consumed for all international maritime journeys (excluding military journeys) for the year 2000. The differences between these studies represent the inherent uncertainties associated with activity-based approaches, which are mainly focussed around input vessel details and the assumed activity level of ships.

A two-phase report for the International Maritime Organization (IMO) was compiled by a consortium of scientists, which included Corbett, Eyring, and Endresen (Buhaug et al., 2008, 2009). These reports presented a consensus fuel consumption value of 208 Mt by all non-military international shipping in 2001 (Buhaug et al., 2008). For the base year of 2007, Buhaug et al. (2009) found that 274 Mt of fuel was consumed by international non-military shipping. This is equivalent to 843 Mt of CO_2 emissions and represents 2.7% of total global anthropogenic CO_2 emissions in 2007. Paxian et al. (2010) estimated a similar figure, 221 Mt of fuel consumed by the 2006 global shipping fleet, using individual ship characteristics and spatially resolved ship movements databases.

The research conducted for the IMO (Buhaug et al., 2008; Buhaug et al., 2009) used both bottom-up and top-down models to compare results and attempted to standardise the methods used when calculating fuel usage and emissions from maritime transportation. The results of such comparisons were that:

> *"...the international team of scientists behind this study concluded that the activity-based estimate is a more correct representation of the total emissions from the world fleet including in national ship registries than what is obtained from fuel statistics."* (Buhaug et al., 2008)

This finding by Buhaug et al. (2008) is at odds with the methodologies endorsed by Eggleston et al. (2006), who endorsed fuel data-based methodologies over activity-based methodologies as being "typically" more reliable.

One of the first attempts at quantifying the international shipping emissions associated with a single country was De Meyer et al. (2008). They investigated the Belgian part of the North Sea, which included territorial sea (out to 12 nm) and the exclusive economic zone, and covered a total area of approximately 3600 km^2. De Meyer et al. (2008) calculated that 1.9 Mt of CO_2 was emitted in that region by all vessels that visited a Belgian port between April 2003 and March 2004, compared to the figure of 22.8 Mt of CO_2 based on bunker fuels sold in Belgium. A similar study by Schrooten et al. (2008) investigated emissions from international shipping in the North Sea out to 12 nm from the Belgian coast, which covered a total area of approximately 1400 km^2. CO_2 emissions of 0.7 Mt were calculated for all vessels that called at a Belgian port for the year 2004, compared with 24.2 Mt estimated from bunker inventories.

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Through a bunker fuels study, Olivier and Peters (1999) found that 5039 petajoules (PJ) of fuel was consumed for international shipping during 1990. This corresponds to 366 Mt of CO_2 or 1.8% of the total global anthropogenic emissions for that year. Attributing these emissions to the country where the bunker fuels were sold resulted in the top three countries being the USA, Netherlands, and Singapore with 23.8%, 9.0%, and 8.8% of the world's total emissions from international shipping, respectively. This provides a good example of how any policy proposal to allocate emissions based on bunker fuel statistics would tend to disadvantage countries that have global hub ports, such as Singapore and the Netherlands, while benefiting land-locked countries, which do not refuel international vessels (Olivier and Peters, 1999).

In the New Zealand context, Smith and Rodger (2009) estimated the emissions from all New Zealand's international visitors arriving by air transport, and for New Zealanders travelling overseas in 2005, to be 4.2 Mt and 2.1 Mt of CO_2, respectively, using an activity-based methodology. Smith and Rodger (2009) included the full journey in both directions for those calculations. This is approximately 2.4 times higher than the 2.630 Mt allocated for the same year by the Ministry of Economic Development (2008a) using a bunker fuels methodology. The only activity-based maritime transport emissions calculations for New Zealand in the peer-reviewed literature that the authors are aware of are contained in Howitt et al. (2010), where it was estimated that all international cruise ship journeys to and from New Zealand in 2007 emitted 0.053 Mt of CO_2. The Ministry for Economic Development (2008a) quantified the CO_2 emissions for all ships that refuelled in New Zealand during 2007 and were journeying internationally as 0.978 Mt, based on the consumption of fuels bunkered for international maritime transport. In 2007, 99.5% of all products (by mass) were imported to or exported from New Zealand by sea (Statistics New Zealand, 2007). The research contained in this paper therefore adds to the international literature comparing methodologies, and also adds to the knowledge around the structure of New Zealand's international trade.

2. Policy context

The Kyoto Protocol focusses on the reduction of greenhouse gas emissions, which can be achieved through pollution-control measures (such as cleaner fuel) and also through measures to improve energy conservation. However, despite the contribution of maritime transport to greenhouse gas emissions, international maritime transport was excluded from national reduction targets under the Kyoto Protocol. International aviation was also excluded, although national air and sea transport were included. Article 2.2 reads:

"The Parties included in Annex 1 shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively." (United Nations, 1998)

There are three important points to note in Article 2.2:

(i) The clause only mentions Annex I Parties, which is the list of "developed" countries given in the Kyoto Protocol;
(ii) The clause specifies emissions from the burning of "bunker fuels" as its focus;

(iii) The Annex I countries are to work through the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO).

Point (i) is consistent with the rest of the Kyoto Protocol, which recognised the principle of "Common But Differentiated Responsibility" (CBDR), where Annex I countries are obliged to make reductions in recognition of their contribution to the existing greenhouse gas loading on the atmosphere through their historical industrialisation, and also in recognition of their capacity to respond. However, point (iii) obliges these countries to work through IMO for maritime transport, and IMO has a policy of "no less favourable treatment of ships", meaning that any policies must treat all ships from all countries equally. The tension between the CBDR implications of point (i) and the equal treatment policy of point (iii) has occupied much of IMO's time and energy in dealing with negotiations arising out of Article 2.2 (for example, see Carbon Positive (2010)).

Point (ii) has, traditionally, been taken to imply that any methodology to calculate emissions, and any process to allocate responsibility for these emissions, should be done through bunker fuel statistics. These statistics specify how much fuel is stored and subsequently consumed for national and international transport. As will be discussed below, the accuracy of the bunker fuels methodology has been challenged (Corbett and Koehler, 2003; Eyring et al., 2005; Buhaug et al., 2009).

Note that there was no timeline attached to Article 2.2, and no specific percentage or mass-value target was attached to the "limitation or reduction" phrase, and IMO and ICAO have been criticised for their lack of progress on this issue (e.g., Oberthür, 2003).

The United Nations Climate Change Conference at Copenhagen in December 2009 did not alter the present arrangements for addressing greenhouse gas emissions from international transport. The IMO continues to be the regulatory body responsible for developing policy measures to reduce greenhouse gas emissions from international shipping.

The IMO have investigated several different policy measures that all aim to reduce emissions from international shipping; four of these options are discussed in the paragraphs below. Note that the policy options discussed are all in the planning and discussion phase in the IMO, and there is a potential to use more than one option.

By using an efficiency measure of grams of CO_2 emitted per tonne-kilometre of goods transported (g CO_2 per t-km), the IMO have been developing the Energy Efficiency Design Index (EEDI) for all newly built ships. The EEDI would take into account the reduction in fuel use that could be attained by the better design of several vessel features, such as optimising the hull and propeller design for increased efficiency (Buhaug et al., 2009). The IMO could either enforce a mandatory limit on an EEDI, which would impose penalties on ships which exceed the limit, or require reporting on EEDI, which may lead to increased overall efficiency if there are the right incentive schemes in place (Buhaug et al., 2009). It is likely that the benefits of the introduction of EEDI limits below current fleet averages would not appear until 2020 (IMO, 2010).

Due to the relatively small proportion of new ships to ships currently in operation, the most significant option to reduce emissions from the global shipping industry comes from the improved operation of existing ships. An Energy Efficiency Operational Indicator (EEOI) would take into account the energy that could be potentially saved from the enhanced operation of current ships, and could be used as the qualitative 'yardstick' for the development of a Ship Energy Efficiency Management Plan (SEEMP) (Buhaug et al., 2009; IMO, 2010). Similarly to the EEDI, the IMO could impose the mandatory use of a SEEMP or mandatory limits on the EEOI value, which would include penalties for non-compliance, or require reporting on the use of a SEEMP or the values of the EEOI for ships (Buhaug et al., 2009). The IMO recently reported that it did not see the mandatory use of a SEEMP and EEOI in the “foreseeable future” (IMO, 2010). The use of one, or a combination of an EEDI, EEOI or a SEEMP, would directly decrease the amount of fuel used, and therefore emissions, by using more efficient technology and operational procedures on international cargo vessels. The two further policy options discussed below, however, are market-based mechanisms that aim to indirectly decrease the amount of fuel used by increasing the incentive (by way of cost) for increased energy efficiency.

One market-based mechanism discussed by the IMO is a maritime emissions trading scheme (METS) of CO_2 (Buhaug et al., 2009). A METS would be a cap and trade type system, where the price of carbon is controlled by the market. If a ship or company emits more than its allocated amount, then they would have to purchase carbon credits. These credits could be purchased from other ships or companies within the sector, or even from unrelated companies from other sectors, which emit less than their allocated amount. In a cap and trade system, the cap limits the total emissions. If the cap is set at a suitable level, the market price for carbon credits incentivises reductions in greenhouse gas emissions.

Another possible market-based mechanism is an International Compensation Fund (ICF) (Buhaug et al., 2009). An ICF would consist of a global levy on marine bunker fuels at a set price per tonne of fuel bunkered, based on the emissions factors for the particular fuel. The cost of the levy could be paid by one of three parties; the ships, the bunker fuel suppliers, or the oil refineries and would drive reductions in overall greenhouse gas emissions in a similar way to the METS (Buhaug et al., 2009).

Any of the above policy options will require accurate quantification of emissions at all levels of the sector. This paper presents a case study of an activity-based analysis to calculate the total fuel consumption, and subsequent greenhouse gas emissions, associated with the international maritime transportation of New Zealand’s imports and exports during 2007. This paper will help inform discussions of how such methodologies can impact on policy decisions.

3. Methodology

3.1 Overview

A cargo-based approach was used in the current study to calculate the fuel consumption associated with New Zealand’s international maritime transport of goods. The total fuel consumption is the sum of fuel consumed by the main and auxiliary engines from all vessels’ cargo-carrying journeys. From the total fuel consumption, emissions factors (*EF*) were then applied for each of the eight pollutants CO_2, NO_X, SO_2, CO, PM_{10}, NMVOC, CH_4, and N_2O, to calculate the quantity of each emitted. Calculations of fuel use and emissions were first calculated for all plant, animal, and food products. These results were then extrapolated to all imports and exports, as explained more fully in subsection 3.4.

To calculate the greenhouse gas emissions associated with the international maritime transport of New Zealand’s 2007 imports and exports, a range of information was gathered. The information needed is outlined below:

● The names/identification numbers of cargo-carrying vessels that visited New Zealand for a given calendar year.
● The origin and destination of each cargo type, on each journey, and any intermediate points travelled through, and hence the distance travelled.
● The mass of each cargo type on each vessel.
● The rated power of the main and auxiliary engines of each vessel.
● The speed at which each ship travelled between the origin and destination.
● The average load on the main and auxiliary engines, as a percentage of the maximum rated power of the corresponding engine, when travelling at sea.
● The emissions factors for each pollutant.
● The maximum cargo capacity of each vessel.
● The mass of New Zealand cargo.

The applied methodology is broken down into the following subsections where; the equations used are presented (subsection 3.2), the sources of the information are discussed (subsection 3.3), the calculation process is explained (subsection 3.4), and finally the uncertainties associated with the methodology are outlined (subsection 3.5).

3.2 Equations

Fuel consumption estimates for both main and auxiliary engines were calculated for each individual product's journey for all plant, animal, and food products (Product Description (PD) dataset – see subsection 3.3) by using Eq. (1), below, which was adapted from the methodology used in Buhaug et al. (2009).

$$FC = P \times \frac{D}{v} \times \%MCR \times SFOC \times \frac{m_{NZ}}{m_{Total} \times U} \quad (1)$$

Where:
FC is the fuel consumption in grams (g);
P is the maximum installed engine power of the main or auxiliary engine(s) in kilowatts (kW);
D is the distance travelled by the vessel in nautical miles (nm);
v is the mean cruise speed of the vessel in knots (nm/hr);
%MCR is the mean load on the main or auxiliary engine(s) as a fraction of the engines' maximum installed engine power, where *MCR* stands for 'Maximum Continuous Rate';
SFOC is the specific fuel-oil consumption rate, in grams of fuel consumed per kilowatt-hour of engine output (g/kWh);
m_{NZ} is the mass of individual products imported to or exported from New Zealand onboard each vessel voyage in tonnes (t);
m_{Total} is the maximum cargo capacity of each vessel in tonnes (t);
U is the mean utilisation fraction of each vessel's cargo capacity, which Buhaug et al. (2009) calculated by dividing the mean total mass of all cargo onboard a vessel by its maximum cargo capacity (i.e., how heavily loaded the vessel was).

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The fuel consumption for each product's journey in the PD dataset was summed over all journeys and then extrapolated by mass-distance to the complete imports and exports dataset (ten-digit Harmonised System (HS10) dataset, see subsection 3.3). From this, the emissions of each pollutant could be calculated by using Eq. (2), below.

$$E_X = FC_{Total} \times EF_X \qquad (2)$$

Where:
E_X is the total emission of pollutant X in grams (g);
FC_{Total} is the total fuel consumption in grams (g);
EF_X is the emissions factor for pollutant X in grams of pollutant per grams of fuel consumed (g/g).

3.3 Data sources and derived information

The core data used in this study consisted of three different datasets relating to New Zealand's maritime trade in the 2007 calendar year. The first dataset contained journey details of all internationally travelling vessels that visited New Zealand in 2007, and was sourced from the New Zealand Customs Service. This information was derived from the 'Advance Notice of Arrival' (ANA) form that all ships entering New Zealand from an overseas destination must submit before they arrive. The relevant data fields from this dataset included: vessel name, IMO number, last overseas port and country, first and last New Zealand port of call and the next overseas port and country. Arrival and departure times were validated against port records which were obtained from the port companies (CentrePort, 2009; Port of Napier, 2009; Northport, 2008; Port Taranaki, pers. comm., 16 December 2008; Port Tauranga, pers. comm., 12 December 2008; Ports of Auckland, pers. comm., 6 January 2009). From this dataset, the journey of each vessel from the last overseas port to a New Zealand port, and from a New Zealand port to the first overseas port, could be determined.

The second core dataset was obtained from Statistics New Zealand and was an HS10 dataset that itemised all New Zealand's international import and export cargo transported by sea in 2007. New Zealand uniquely identifies imported and exported goods by using a ten-digit Harmonised System (HS10) code. The first two digits of the harmonised system code (HS2) are known as 'chapters', numbered 01 to 99, which form the most general classification of goods. The Harmonised System is internationally standardised, and represents a common method of classifying traded products worldwide. The HS10 data from Statistics New Zealand is derived from Product Declarations (PD), which are lodged with the New Zealand Customs Service for all imported and exported goods. HS10 data does not include all the details of the PD data, as Statistics New Zealand remove commercially sensitive information and also filter and perform quality control checks on the input data, particularly at the HS2 level (Statistics New Zealand, pers. comm., 2 February 2010).

A third core dataset was needed to calculate the total mass of New Zealand cargo onboard an individual vessel's journey and needed to also include individual vessel names, and arrival and departure dates for each journey. The identification of individual vessels is necessary for the approach used in this paper. The arrival and departure dates are needed to link each vessel journey with the ANA data, which allows a distance to be calculated between origin and destination with another port in between, to more fully represent the journey distances. These details are present in the PD dataset, a subset of which was obtained from the

New Zealand Customs Service and makes up the third core dataset used in this study. This subset of PD data included plant, animal and food products (the first 21 chapters of the HS10 code, see appendix). The acquired PD data fields included: tariff heading (first four digits of the HS10 code), total gross mass, date of import or export, craft name, voyage number, port of loading name and code, and port of discharge name and code. A random fraction of the products' gross masses were validated against a database at Port Otago (pers. comm., 14 July 2009).

Three online distance calculators (Dataloy Distance Table, World Shipping Register Sea Distance Calculator, and Netpas Distance) were compared against each other for calculating the distances between ports. All three calculators agreed with each other to within ±1%. Due to the greater number of waypoints and logical relations between waypoints, the Dataloy Distance Table (Dataloy, 2009) was considered to be the most accurate and was subsequently used in this study to calculate all the international port-to-port distances.

Vessel specific data was obtained from Lloyd's Register-Fairplay Ltd. (2009), which included each vessel's cruise speed, main engine size, auxiliary engine size, deadweight tonnage (DWT) and year built. Where Lloyd's Register-Fairplay Ltd. (2009) was missing data, a model was used to estimate the desired value. For example, auxiliary engine size data was not available for 62 of the 292 vessels in this study. These were estimated for each vessel based on the relationship between the known main and auxiliary engine sizes within each vessel type category. Note that due to financial limitations, only the data outline above was available, and this study therefore did not have access to more comprehensive ship movements databases.

Actual maximum cargo capacities (m_{Total}) and utilisations (U) for each vessel could not be obtained due to commercial sensitivity. A model was therefore developed to estimate these values based on the available data. Each vessel's maximum cargo capacity (m_{Total}) was estimated as 80% of its DWT, an assumption used in Corbett and Fischbeck (2000). DWT is a measure of the maximum mass (in tonnes) that a vessel can safely carry and includes the total mass of fuel, crew, fresh and ballast water and other provisions, as well as the mass of cargo. Therefore, the maximum cargo capacity should always be lower than the DWT of a vessel. The mean utilisation (U) of each vessel, which describes the mean mass of cargo onboard as a fraction of the maximum amount of cargo a vessel could carry, was assigned the average yearly capacity utilisation value for the corresponding vessel type category as published in Buhaug et al. (2009). These values ranged from 45% for product tankers less than 10,000 DWT to 70% for all container vessels.

Specific fuel oil consumption rates (*SFOC*) for each vessel were determined from the rated power of the main or auxiliary engines, the vessel's age (Lloyd's Register-Fairplay Ltd., 2009) and the SFOC values provided in Buhaug et al. (2009).

There are variations within the literature on standardised emissions factors (*EF*) as these can vary by fuel type and engine performance (Eggleston et al., 2006). To remain consistent with other input variables, the most recent emissions factors have been used in this study from Buhaug et al. (2009). These values were originally derived from several sources, including the IPCC and the Core Inventory of Air Emissions (CORINAIR), and were agreed on by a consortium of expert scientists on behalf of the IMO (Buhaug et al., 2009). The emissions factors of CO_2, SO_2 and PM_{10} vary depending on fuel type and the emissions factor of NO_X varies depending on engine speed. In order to calculate an average global emissions factor for each of these pollutants, mean fuel and engine types were used (Buhaug et al., 2009). For example, the emissions factors for CO_2 in Buhaug et al. (2009) are 3.13 tonnes of CO_2 per tonne of residual fuel oil (or Heavy Fuel Oil, HFO) burnt and 3.19 tonnes of CO_2 per tonne of Marine Diesel Oil (MDO) burnt. The "best estimate" of total global fuel consumption in 2007 comprised of 77% HFO and 23% MDO (Buhaug et al., 2009), and so the CO_2 emissions factor used in the current study was: 0.77×3.13 + 0.23×3.19 = 3.144 tonnes of CO_2 per tonne of fuel burnt.

The average load on the main and auxiliary engines as a percentage of their maximum continuous rates (*%MCR*) for each vessel were assigned the values published in Buhaug et al. (2009) for each vessel type category.

3.4 Carrying out the calculations

Only the PD data (not the HS10 data) could be linked to the ANA data, meaning that the journeys could be linked to both an intermediate overseas port between the origin and destination and a particular vessel. Therefore, the distances had to first be calculated for the PD data and then applied to the origin/destination pairs from the HS10 data, in that order. Since particular vessels could be identified, a more accurate calculation of the emissions for the PD data was obtained. The process was therefore to first calculate the emissions for the PD data, and then extrapolate it to the HS10 data for which a particular vessel was not known. Fuel was calculated first and then emissions factors per mass unit of fuel consumed were applied. Because the same emissions factors were used for both data sets, it did not make a difference to the overall emissions whether the emissions factors were applied before or after the extrapolation.

Because there are many final destinations for goods travelling on each vessel's initial voyage (from a New Zealand port to the first overseas port), the distances travelled by each commodity from the first overseas port to their corresponding final destination were weighted by the mass of each commodity and then the mean was taken to calculate an overall distance. The calculated distance therefore represents an effective distance travelled by all commodities onboard; this means that one loading factor, calculated as the vessel enters or exits New Zealand can be applied to the entire journey.

Individual maritime voyages were identified from PD data and the masses of all New Zealand imports and exports (m_{NZ}) onboard were calculated for each specific journey. This was divided by the mean maximum cargo capacity (m_{Total}) times the average utilisation (U) to calculate the proportion of cargo onboard each vessel which was related to New Zealand's international trade, as shown by Eq. 1. In addition to this, the total amount of fuel used by, and therefore the subsequent emissions from, each vessel's journeys was calculated. This is the equivalent of assuming that each vessel was loaded to its capacity ($m_{Total} \times U$) with New Zealand cargo, by the methodology used in the current study. Furthermore, a lower limit to the amount of fuel use and emissions was calculated by assuming that each vessel was loaded to 100% utilisation, so the total weight of cargo onboard was the maximum capacity of each vessel, therefore decreasing the New Zealand proportion of the total cargo mass. Note that the calculation discussed above is for the PD data only, and therefore only includes goods in the first 21 chapters of the HS10 code. This leads to a much lower New Zealand proportion of cargo than if all goods were considered, due to vessels generally containing a vast range of goods. As a separate calculation, the overall mean New Zealand proportion of cargo was determined from the ANA and HS10 datasets. Of the 10 categories of ships listed in the ANA data, cruise liners, fishing boats, tugs, oil rig supply vessels, and specialised craft that did not

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appear in the PD dataset were excluded from all calculations performed in this research, as they do not generally carry cargo. The subset of PD data used in this research supports this assumption, as only the following five vessel types were used in the transportation of plant, animal, and food products in 2007: bulk carriers, chemical tankers, container ships, general cargo ships, and refrigerated cargo ships. The total mass of all goods detailed in the HS10 dataset for imports and exports were divided by the sum of each vessel's $m_{Total} \times U$ for all import and export journeys in the ANA data.

3.5 Uncertainties

The current cargo-based model has a degree of uncertainty associated with every input value which it uses. A summary of these inputs and a qualitative description of their confidence and uncertainty are provided in Table 1.

Table 1. Confidence in input variables for the cargo-based model for New Zealand's internationally traded plant, animal, and food products (PD data).

Input Variable	Data Source	Confidence	Comments
Main and Auxiliary Engine Power (P)	Lloyd's Register-Fairplay Ltd. (2009) for all ME's and 79% of AE's; 21% of AE's were modelled from the known data.	High	The models used to estimate AE's were based on many known values and only corresponded to a small percentage of the total installed power of all engines.
Distance (D)	Dataloy Distance Table (2009)	Moderate	High accuracy of calculator. Uncertainty arises from unknown global rotation of vessels.
Cruising Speed (v)	Lloyd's Register-Fairplay Ltd. (2009)	Moderate	Uncertainty arises from not knowing how close to the cruise speed provided in Lloyd's Register-Fairplay Ltd. (2009) each vessel actually travels.
Engine loadings ($\%MCR$)	Buhaug et al. (2009)	Poor	Average vessel category values applied. Dominates uncertainty in Buhaug et al. (2009) out of all values used.
Specific Fuel Oil Consumption rate ($SFOC$)	Buhaug et al. (2009)	High	Some engine variability although average values considered accurate. All input data available to select correct value.
Emissions Factors (EF)	Buhaug et al. (2009)	High-Moderate	Uncertainty in applying global average values to the vessels that visited New Zealand. Small variations exist within the literature on emissions factors.
Mass of New Zealand cargo on voyage (m_{NZ})	New Zealand Customs Service and Statistics New Zealand (2007)	High-Moderate	Datasets do not exactly agree with each other. Uncertainty in identifying the specific voyage cargo transported on within the Customs data.
Maximum cargo capacity of vessel (m_{Total})	Corbett and Fischbeck (2000)	Moderate	Unknown as to how close to 80% of each vessel's DWT the maximum cargo capacity is.
Cargo utilisation (U)	Buhaug et al. (2009)	Poor	Average vessel category values applied. Large uncertainties for individual voyages for various reasons.

The uncertainties surrounding exact vessel journeys, and the ports which they visited, also meant that manoeuvring and port activities were not included in the current model. Whall et al. (2002) reported that in port emissions (which included manoeuvring, loading/unloading and hotelling) contributed to 6% of the total CO_2 emissions calculated in their study. Whall et al. (2002) considered only ship movements within the European Community, therefore the expected contribution of port activities to the overall emissions as calculated in this study is likely be less than 6%. This is because the average journey length is much longer for vessels completing an international journey to or from New Zealand when compared to journeys between ports in the European Community. Preliminary calculations indicated that port activities only contributed to approximately 1% of the total fuel use and emissions for each journey leg, and were therefore considered to be negligible.

The available data did not provide enough information to follow the exact global route taken by all vessels which visited New Zealand during 2007. This produces uncertainty in the total distance travelled, and therefore the time taken, for each vessel's journey if the goods onboard did not originate from, or were destined for, the first or second port of call either side of New Zealand. Actual schedules were obtained for several vessels (Maersk, 2009), which revealed that approximately 40% of imported and 80% of exported products by mass originated from, or were destined for, the first or second port of call either side of New Zealand for these vessels. The remaining products were not sourced from, or destined to, any of the ports which were visited by these vessels. This indicates that the goods must have changed vessel at some point and could therefore no longer be tracked with the available data. Additional information about trans-shipped cargo and global cargo movements would be required if an accurate distance is to be calculated for all transported goods. Global Positioning System (GPS) data sets, such as the Automated Mutual-assistance Vessel Rescue (AMVER) system used by Eyring et al. (2005), include detailed ship movements, but do not include information that could be used for tracking movement of cargo onto other vessels after departure. Due to this lack of accurate cargo tracking, the current research potentially underestimates the distances travelled by commodities between origin and destination, and therefore the journeys' durations. Although this uncertainty cannot be quantified, it alone would lead to an overall underestimate of the emissions as calculated in this paper. Due to the lack of data available about the path travelled by vessels under various weather conditions, the effect of weather routing has not been included in the present study. This creates an additional uncertainty in the distance travelled due to some vessels travelling a different route due to weather phenomena.

4. Results and Discussion

Due to the issues discussed earlier, the sum of the masses of all New Zealand's imports and exports categorised by the first 21 chapter headings of the HS10 code in the HS10 dataset did not agree with the total masses of New Zealand's imports and exports given in the PD subset (which included only the first 21 chapters of the HS10 code). When the relevant total masses were calculated for the initial datasets, the PD data contained 12% more mass overall than the first 21 chapters of the HS10 dataset. In total, 361 of the initial 248,371 import and export rows of data in the PD dataset were excluded. These were excluded based on input data being missing or containing errors, such as the mass of good being transported being recorded as 0 kg, or when the mass recorded was too high; in one such example the recorded mass of exported molluscs was 13 times heavier than the DWT of the vessel carrying them. As a result of these exclusions, the difference in the total mass contained in modified PD data compared to the first 21 chapters of HS10 data was reduced to 5.4% (Table 2).

Table 2. Total masses of goods, before and after the exclusion of erroneous or incomplete data rows.

	Before Exclusions			**After Exclusions**		
	Imports	**Exports**	**Overall**	**Imports**	**Exports**	**Overall**
Total PD dataset mass (tonnes)	1,971,233	5,704,457	7,675,690	1,818,519	5,387,900	7,206,419
HS10 dataset mass of goods (chapters 1-21) (tonnes)	1,636,801	5,200,806	6,837,607	1,636,801	5,200,806	6,837,607
Percent difference (with HS10 as the base)	20.4%	9.68%	12.3%	11.1%	3.60%	5.39%

By taking into account the maximum cargo capacity and the mean utilisation of individual vessels in the ANA dataset and the total mass of New Zealand cargo being transported in the HS10 dataset, the overall mean proportion of a vessel’s activity relating to New Zealand’s international trade of goods was calculated. From all of the international maritime vessels which visited New Zealand in 2007, 73% of their activity (by mass) was directly linked to New Zealand’s imports and exports. This is shown in Table 3, which also shows the relative proportions of New Zealand cargo if all cargo onboard was assumed to be New Zealand cargo and the lower limit of the New Zealand proportion. To estimate the lower limit of the New Zealand proportion, it was assumed that each vessel had a utilisation of 100%, and so the cargo carried on each journey was each vessel’s calculated maximum cargo capacity; 80% of each vessel’s DWT. Table 3 shows that the New Zealand proportion of cargo contributes to 64% of a vessel’s mean load (by mass) for arriving vessels, but 81% of the mean load on departing vessels. This means that vessels are more heavily loaded with New Zealand cargo when they depart New Zealand compared to the mass of New Zealand imports when they arrive.

Table 3. Vessel activity by mass for New Zealand’s internationally traded goods (2007).

	Upper Limit	**New Zealand Proportion**	**Lower Limit**
Imports	100%	64%	39%
Exports	100%	81%	50%
Overall	100%	73%	45%

The cargo-based model was used to calculate fuel consumption values, and an approximation of their lower limit, for the transport of New Zealand’s imported and exported plant, animal, and food products in 2007, given by the subset of PD data (Table 4). The upper limit has not been quantified as the mass of products not detailed in the first 21 chapters could not be linked to a vessel. The total vessel fuel use (Table 4) is, therefore, an indication of the total amount of fuel consumed by all vessels which carried plant, animal, and food products, although these vessels may have also carried other products. For this reason, the total vessel fuel use should not be considered as an upper limit to the amount of fuel consumed by the transportation of plant, animal, and food products. The mean distance travelled by the plant, animal, and food imports and exports in the PD data was 11,400 km, and the overall mean rate of fuel consumption was 5.5 grams per tonne-kilometre (g per t-km), as shown in Table 5.

Table 4. Fuel consumption estimates for all of New Zealand's internationally traded plant, animal, and food products in 2007 (PD data). Note: All values rounded to three significant figures from calculations.

(tonnes)	Total Vessel Fuel Use	Proportion associated with New Zealand's plant, animal and food transports	Lower Limit of New Zealand Proportion
Imports	721,000	70,200	43,900
Exports	859,000	384,000	249,000

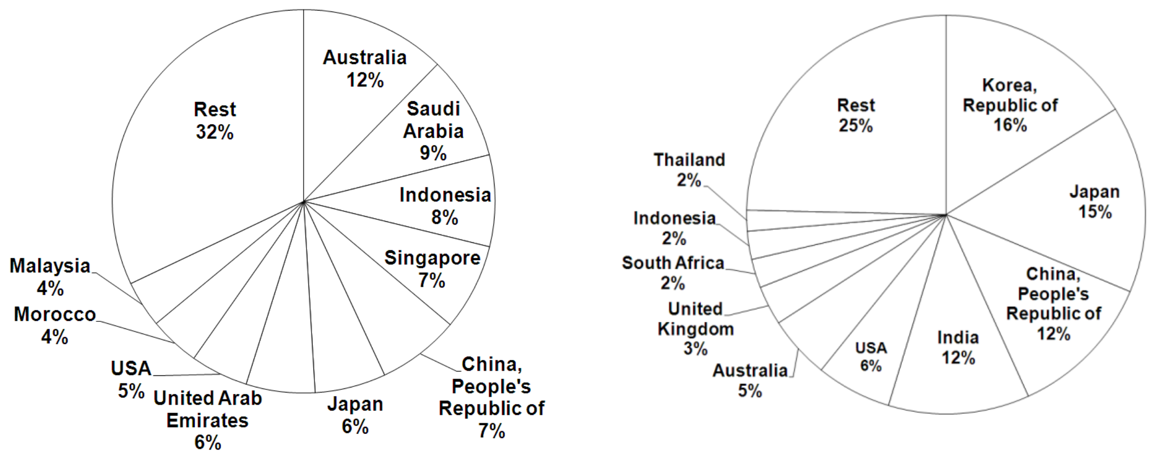
Table 5. Values derived from commodity analysis for internationally traded plant, animal, and food products in 2007 (PD data). Note: All values rounded to three significant figures from calculations, except the final column where values have been rounded to two significant figures.

	PD Mass (tonnes)	Weighted Mean Distance Travelled (km)	Total New Zealand Proportion Fuel Consumption (tonnes)	Mean Fuel Consumption Rate (g/tonne-km)
Imports	1,820,000	7,900	70,200	4.9
Exports	5,390,000	12,600	384,000	5.6
Overall	7,210,000	11,400	454,000	5.5

The calculated mean overall fuel consumption rate can be converted into a New Zealand specific maritime CO_2 emissions factor for all internationally traded plant, animal, and food products of 17 g of CO_2 per t-km. The DEFRA (2008) report provides emissions factors ranging from 4 to 20 g of CO_2 per t-km for eight different vessel categories, assuming that they are all fully loaded. The mean CO_2 emissions factor found in this study is higher than all categories except for 'small tanker' in the DEFRA (2008) report, which is in part due to the assumed reduced loading factors of actual vessels. Similarly, Buhaug et al. (2009) estimate the mean CO_2 emissions per t-km for 42 different categories of the global cargo vessel fleet.

Their results ranged from 2.5 g of CO_2 per t-km for large bulk carriers to 60.3 g of CO_2 per t-km for small roll-on, roll-off (ro-ro) vessels. Container vessels transported 79% of the overall total tonne-kilometres (with refrigerated cargo ships being the next highest contributor at 9% of the overall total tonne-kilometres) for the plant, animal, and food products contained in the PD dataset in 2007. For percentages of refrigerated cargo carried by each ship type, see Fitzgerald et al. (in press). The range of CO_2 emissions per t-km for container vessels in Buhaug et al. (2009) was between 12.5 and 36.3 g of CO_2 per t-km and the emissions factor found in this research lies within this range, providing some validation for the value obtained.

Due to the HS10 dataset having quality control checks on its input data, the complete HS10 dataset was used as the basis for which the PD data subset was extrapolated. HS10 data contained information on the New Zealand port of entry/departure and the overseas port of origin/destination for individual products, but did not detail the transporting vessel, thereby preventing it from being linked to the ANA data. Approximate distances were therefore applied to the HS10 dataset by taking the mean of all mass-weighted distances in the PD data with the same origin and destination. Variations in distances and vessel specific inputs are ignored by this method, and will produce errors if these variables are not well represented in the subset of PD data obtained. The total mass of the first 21 chapters of goods in the HS10 dataset corresponded to 9% of all imports and 22% of all exports of the full HS10 dataset. Weighting the HS10 data by mass distance changed the represented proportion to 7.5% of all imports and 25% of all exports, which was considered to be a more realistic approach than extrapolating by mass alone. These percentages were applied to the New Zealand proportion of PD data and the upper and lower limits were calculated based on the relative New Zealand proportion of cargo shown in Table 3. This extrapolation is only intended to provide an indication of the total fuel use and greenhouse gas emissions linked to New Zealand's 2007 international maritime trade.



Figures 1a and 1b; Country of origin and destination proportions of total mass-distance for New Zealand's imported and exported products, respectively, for the year 2007. The total mass-distance for imports is 1.8×10^5 Mt-km, and for exports it is 2.6×10^5 Mt-km.

For the year 2007, Figure 1a shows that most of New Zealand's mass-distance proportion of imported products came from within the Asia-Pacific and Middle East regions. Similarly, Figure 1b indicates that the majority of the mass-distance proportion for exports was from products shipped to countries within the Asia-Pacific region.

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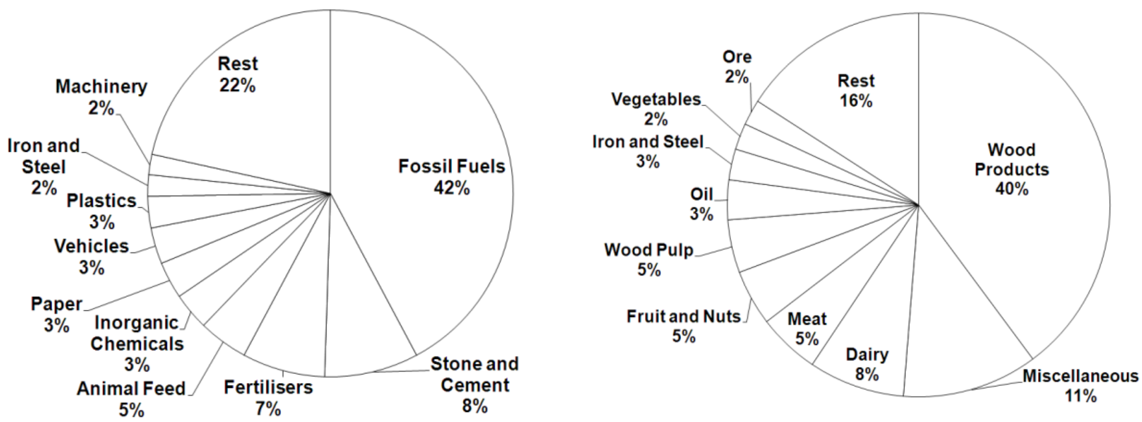

Figures 2a and 2b; Commodity proportions of total mass-distance for New Zealand's imported and exported products, respectively, for the year 2007. The total mass-distance for imports is 1.8×10^5 Mt-km and for exports it is 2.6×10^5 Mt-km.

The total mass of goods transported by sea to and from New Zealand in 2007 was 41 Mt, of which approximately 56% was exports. Figure 2a shows that the major New Zealand import on a mass-distance basis in 2007 was fossil fuel products. For exports, Figure 2b indicates that wood products were a significant export on a mass-distance basis. The "Miscellaneous" category in New Zealand's exports (Figure 2*b*) was investigated further; exports from Lyttelton contributed to 83% of the total mass (90% of the total mass-distance) of this category, and through an analysis of the mass values given in Solid Energy Limited (2008), these ex-Lyttleton exports are highly likely to have been coal exported by Solid Energy Limited during this period. Note that the title of each commodity given is an abbreviation of each of the chapter titles of the HS2 code. The full chapter title of each commodity is given in the Appendix.

Extrapolated results, along with the upper and lower limits of the New Zealand proportion of fuel use and emissions (based on the modelled New Zealand cargo proportion) are shown in Table 6, broken down into imports and exports. Table 6 shows that a total of 2.5 Mt of fuel was consumed in the international shipping of commodities to and from New Zealand in 2007. This is equivalent to approximately 2.6 billion litres or 107 PJ of energy, based on the fuels' gross calorific values presented in the New Zealand Energy Data File (Ministry of Economic Development, 2008b). The amount of fuel consumed corresponds to 7.7 Mt of CO_2 emissions, based on mean fuel types, engine speeds, and vessel utilisations. Total emissions of NO_X, SO_2 and CH_4 are equivalent to 180,000 tonnes, 110,000 tonnes, and 740 tonnes, respectively. Table 6 also shows that approximately 62% of all fuel use and emissions are related to exports and the remaining 38% are related to imports.

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Table 6. Fuel use (tonnes) and greenhouse gas emissions (tonnes) from the international transport of goods to and from New Zealand in 2007, extrapolated by mass distance to HS10 data.

(tonnes)	Imports	Exports	Total	Upper Limit	Lower Limit
Fuel consumed	935,000	1,520,000	2,450,000	3,320,000	1,510,000
CO_2	2,940,000	4,770,000	7,700,000	10,400,000	4,740,000
NO_X	69,200	112,000	181,000	246,000	112,000
SO_2	41,100	66,700	108,000	146,000	66,400
CO	6,920	11,200	18,100	24,600	11,200
PM_{10}	5,050	8,190	13,200	17,900	8,150
NMVOC	2,240	3,640	5,880	7,970	3,620
CH_4	280	455	735	996	453
N_2O	74.8	121	196	266	121

The major uncertainty in this study is the extrapolation of the emissions from the transportation of plant, animal and food products to the transportation of all goods. The extrapolation process introduces additional uncertainties due to the transportation of all goods, in effect, being assigned the same fuel consumption rate per t-km as that calculated for plant, animal and food products. As mentioned, variations in distances and vessel specific inputs are ignored by this method. The studied transportation of plant, animal, and food products was predominantly undertaken by container vessels (79% of the total tonne-kilometres), which were shown in Buhaug et al. (2009) to have a different CO_2 emissions factor than other vessel types. As an example, from the HS10 data, and the mean distance between each origin and destination in the PD data, it was estimated that 42% of the total mass-distance of all New Zealand’s imports in 2007 were fossil fuel products (mostly crude oil), which are almost always carried by tankers. Tankers did not appear in the PD data as they do not carry any plant, animal and food products, but were included in the ANA data. For tankers within the DWT range in the ANA data, the CO_2 emissions factor in Buhaug et al. (2009) is between 4.4 and 33.3 g of CO_2 per t-km, a large variation from the overall mean of 17 g of CO_2 per t-km found for the transportation of plant, animal, and food products.

Sensitivity analysis was also carried out on other input data, which showed that the greatest potential difference in the overall results came from the different emissions factors for sulphur dioxide (SO_2) and particulate matter (PM_{10}) for marine diesel oil (MDO) and heavy fuel oil (HFO). When compared to HFO, MDO has emissions factors for SO_2 and PM_{10} that are 81% and 84% less, respectively. However, due to the global mean emissions factors being used, the emissions calculated are assumed to be representative of the actual proportion of fuel burnt. Further sensitivity analysis on other input data, such as other emissions factors and SFOC rates, found small variations that were considered to be relatively minor when compared to the unquantifiable uncertainty associated with the extrapolation process.

5. Conclusions and Recommendations

This study has outlined a method of calculating international maritime emissions for individual countries, based on the country's imported and exported goods. The limitations and uncertainties of the approach used in the current research have been included in detail and demonstrate the importance of reliable and accurate input data.

Results calculated for fuel use and greenhouse gas emissions for plant, animal, and food products were extrapolated by mass-distance to all imports and exports based on data obtained from Statistics New Zealand (HS10). From this extrapolation, it was estimated that a total of 2.5 Mt of fuel was consumed in the process of shipping all New Zealand's international imports and exports in 2007. The corresponding emissions from the overall fuel combustion were 7.7 Mt of CO_2, 180,000 tonnes of NO_X, 110,000 tonnes of SO_2, and 740 tonnes of CH_4. However, uncertainties exist within the available input data that have the potential to alter the values calculated.

The analysis of all goods imported to and exported from New Zealand in 2007 revealed that a mean of 73% (by mass) of all cargo onboard visiting maritime vessels was directly linked to New Zealand. This shows that not all of a vessel's activity should be attributed to the country being visited; studies which assume this are likely to overestimate a single country's share of maritime fuel consumption and emissions. Investigating all imports and exports of a single country will also lead to the double-counting of maritime fuel use and emissions if applied to a global scale without an accepted method of allocation.

A mean rate of fuel consumption per mass of cargo was calculated from modelled results to be 5.5 g per t-km, which corresponded to a CO_2 emissions factor of 17 g per t-km. The mean distance travelled by plant, animal, and food products to or from New Zealand was 11,400 km. This distance is based on all commodities being transported to the next overseas port and then to their final destination by the most direct standard shipping route. The actual distance travelled by commodities will likely be underestimated by this approach, due to the unknown rotation of vessels around the world. However, this method of calculating distances is more accurate than assuming a direct path between origin and destination.

Future research in quantifying the emissions from New Zealand's imports and exports by a similar cargo-based methodology would have to take into consideration the accuracy of the Customs and Statistics New Zealand datasets, as well as their accessibility. The New Zealand Customs Service is currently reviewing their quality control checks, and for other countries these issues would also need to be considered. These two datasets provide the only source of comprehensive import and export data, apart from collecting data from individual shipping lines and suppliers, which would be difficult due to the commercially sensitive nature of the data and the amount of data that would need to be collected. As previously discussed, there is a trade-off in the Customs PD data between the accuracy it provides in identifying individual vessels' journeys, which is vital to performing an activity-based calculation, and the inaccuracies in some of the input mass data. Statistics New Zealand, however, has quality controlled data that includes vessel names and identifying information, although this is less accessible than the PD data. When applying this methodology to other countries, local differences in databases will need to be assessed at the outset.

Using bunker fuel statistics is an internationally accepted methodology of quantifying national emissions under the Kyoto Protocol (Eggleston et al., 2006), but the total CO_2 emissions calculated in the current study (7.7 Mt) is 7.9 times greater than the quantity of CO_2 emissions calculated by the Ministry of Economic Development (2008a) from international maritime bunker fuels. Since the National Greenhouse Gas Inventory does not aim to quantify the emissions from New Zealand's international trade, and since it is extremely likely that such calculations based on international bunker fuel would underestimate the fuel used by New Zealand's international trade, an approach such as that described in this paper is a more accurate way to calculate such emissions. Underestimates of trade-related emissions using calculations based on bunker fuels occur predominantly because most large cargo vessels do not refuel in New Zealand, due to the relative cost of fuel overseas (Port Otago, pers. comm., 20 November 2008; CentrePort Wellington, pers. comm., 16 January 2009). The under-reporting issues pointed out by Buhaug et al. (2009) will also contribute to the difference. The bunker fuel methodology was shown by De Meyer et al. (2008) and Schrooten et al. (2008) to overestimate the emissions relating to Belgium, a country which has major refuelling hubs at Zeebrugge, Antwerp and Ostend. Therefore, it is important to recognise that internationally bunker fuel statistics do not represent the emissions relating to international maritime transport for individual countries. Furthermore, calculations using bunker fuel data for international maritime transport on a global level underestimates the actual amount of fuel used by all international shipping due to under-reporting (Buhaug et al., 2009). It therefore seems that any future policies aimed at allocating fuel use and emissions should use a standardised activity-based methodology instead of bunker fuel statistics.

If there was international agreement that a cargo-based methodology would be used as a global way to allocate emissions, then a standard methodology would have to be implemented to ensure that emissions are not double-counted, as they would be by the methodology of this research (because one country's export is another country's import).

One option that could potentially produce accurate and reliable global fuel use figures involves individual ships reporting their fuel use. This could be used in conjunction with any allocation method to quantify the fuel use and emissions due to ships, the sector, or individual countries. For example, a proportion of an individual vessel's fuel use could be allocated to a certain country if detailed records were kept (and made accessible) of their actual fuel use and the mass/volume of products destined for, or originating from, that country. This method could potentially have some of the issues associated with bunker fuel statistics, pointed out by Buhaug et al. (2009), where there could be a general under-representation of fuel use due to misreporting. Problems also arise due to the commercially sensitive nature of the shipping industry, which could lead to this method not being easy to implement from a policy point of view. In this research, the discrepancies between the masses of goods declared by companies to the New Zealand Customs Service and those actually transported has been noted. Such inadvertent reporting irregularities would also be likely to be an issue if reporting of fuel consumption was required, so that quality control staff and systems would be needed to ensure the robustness of data if such a policy was adopted.

The policy options that are currently being developed by the IMO (Buhaug et al., 2009; IMO, 2010) do not rely on allocating fuel use and emissions to countries. Therefore, the results of this research do not have any direct implications on these policy options. The IMO, however, needs to be cautious of using a global bunker fuel levy (in the ICF market-based scheme) as there could be issues surrounding fuel under-reporting.

It is believed that this paper is the first peer-reviewed study that attempts a complete cargo-based analysis of fuel consumption and greenhouse gas emissions from international shipping associated with a single country. Future policies that aim to quantify international maritime emissions, either globally or for individual countries, should be based on an internationally standardised methodology.

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Appendix – Titles of selected chapters of the Harmonised System code.

01; Live animals.
02; Meat and edible meat offal. (Abbreviated to "Meat" in Figure 2*b*)
03; Fish and crustaceans, molluscs and other aquatic invertebrates.
04; Dairy produce; birds' eggs; natural honey; edible products of animal origin, not elsewhere specified or included. (Abbreviated to "Dairy" in Figure 2*b*)
05; Products of animal origin, not elsewhere specified or included.
06; Live trees and other plants; bulbs, roots and the like; cut flowers and ornamental foliage.
07; Edible vegetables and certain roots and tubers. (Abbreviated to "Vegetables" in Figure 2*b*)
08; Edible fruit and nuts; peel of citrus fruit or melons. (Abbreviated to "Fruit and Nuts" in Figure 2*b*)
09; Coffee, tea, maté and spices.
10; Cereals.
11; Products of the milling industry; malt; starches; inulin; wheat gluten.
12; Oil seeds and oleaginous fruits; miscellaneous grains, seeds and fruit; industrial or medicinal plants; straw and fodder.
13; Lac; gums, resins and other vegetable saps and extracts.
14; Vegetable plaiting materials; vegetable products not elsewhere specified or included.
15; Animal or vegetable fats and oils and their cleavage products; prepared edible fats; animal or vegetable waxes.
16; Preparations of meat, of fish or of crustaceans, molluscs or other aquatic invertebrates.
17; Sugars and sugar confectionery.
18; Cocoa and cocoa preparations.
19; Preparations of cereals, flour, starch or milk; pastrycooks' products.
20; Preparations of vegetables, fruit, nuts or other parts of plants.
21; Miscellaneous edible preparations.
23; Food industries, residues and wastes thereof; prepared animal fodder. (Abbreviated to "Animal Feed" in Figure 2*a*)
25; Salt; sulphur; earths, stone; plastering materials, lime and cement. (Abbreviated to "Stone and Cement" in Figure 2*a*)
26; Ores, slag and ash. (Abbreviated to "Ore" in Figure 2*b*)
27; Mineral fuels, mineral oils and products of their distillation; bituminous substances; mineral waxes. (Abbreviated to "Fossil Fuels" in Figure 2*a*)
28; Inorganic chemicals; organic and inorganic compounds of precious metals; of rare earth metals, of radio-active elements and of isotopes. (Abbreviated to "Inorganic Chemicals" in Figure 2*a*)
31; Fertilisers (Also "Fertilisers" in Figure 2*a*)
39; Plastics and articles thereof (Abbreviated to "Plastics" in Figure 2*a*)
44; Wood and articles of wood; wood charcoal. (Abbreviated to "Wood Products" in Figure 2*b*)
47; Pulp of wood or other fibrous cellulosic material; recovered (waste and scrap) paper or paperboard. (Abbreviated to "Wood Pulp" in Figure 2*b*)

48; Paper and paperboard; articles of paper pulp, of paper or paperboard. (Abbreviated to "Paper" in Figure 2*a*)

72; Iron and steel. (Also "Iron and Steel" in Figures 2*a* and 2*b*)

84; Nuclear reactors, boilers, machinery and mechanical appliances; parts thereof. (Abbreviated to "Machinery" in Figure 2*a*)

87; Vehicles; other than railway or tramway rolling stock, and parts and accessories thereof. (Abbreviated to "Vehicles" in Figure 2*a*)

98; New Zealand miscellaneous provisions. (Abbreviated to "Miscellaneous" in Figure 2*b*)