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CARBON EMISSIONS FROM INTERNATIONAL CRUISE SHIP PASSENGERS' TRAVEL TO AND FROM NEW ZEALAND

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Abstract

Greenhouse gas emissions from international transport contribute to anthropogenic global warming, yet these emissions are not liable under the Kyoto Protocol. International attention is being given to quantifying such emissions. This paper presents the results of research into international cruise ship journeys to and from New Zealand. CO_2 emissions from such journeys were calculated using an activity based, or "bottom-up", model. Emissions factors for individual journeys by cruise ships to or from New Zealand in 2007 ranged between 250 and 2200 g of CO_2 per passenger-kilometre (g CO_2 per p-km), with a weighted mean of 390 g CO_2 per p-km. The weighted mean energy use per passenger night for the "hotel" function of these cruise vessels was estimated as 1600 MJ per visitor night, 12 times larger than the value for a land-based hotel. Using a simple price elasticities calculation, international cruise journeys for transport purposes were found to have a greater relative decrease in demand than plane journeys when the impact of carbon pricing was analysed. The potential to decrease the CO_2 emissions per p-km was examined, and if passenger accommodation was compacted and some luxury amenities dispensed with values similar to those of economy-class air travel were obtained.

Keywords

Greenhouse gas emissions; cruise ship tourism; international transport.

Background, Policy Context, and Aims

A 2009 report for the International Maritime Organization (IMO) estimated that about 2.7% of the world's total CO_2 emissions in 2007 came from international shipping (Buhaug et al., 2009). The burning of oil (mostly in the form of heavy fuel oil, as well as marine diesel oil) on international vessels releases mainly CO_2, SO_2, NOx and hydrocarbons into the atmosphere. In addition, a number of other substances, such as particulate matter, are emitted to a lesser degree, but are important in assessing climate and environmental impacts. CO_2 and hydrocarbons (including methane) are well known greenhouse gases whose influences on global warming are well documented, and lead to a positive radiative forcing. The short term effect of the other gases results in a negative radiative forcing and therefore implies cooling (Buhaug et al., 2009). For example, the emission of SO_2 and particulate matter help seed cloud formation along a vessel's route, leading to formations known as ship tracks, which decreases the amount of incoming solar radiation incident on the surface below (Schreier et al., 2006). However, balancing the short term effects with the long term effects, the net effect of all emissions from international shipping in the long term contribute to anthropogenic global warming and a positive radiative forcing (Buhaug et al., 2009). The climate impacts of international passenger transport by sea and by air is gaining increasing awareness amongst tourists, tourism operators, governments, and other organisations internationally.

International transport emissions are not liable under the current Kyoto Protocol regime. However, if Kyoto is superseded by a replacement protocol when it expires in 2012, countries or the sector may be liable for their international transport emissions, and so there is a need to quantify these emissions.

Buhaug et al. (2009) include a breakdown of the total number of vessels in the world fleet in each vessel category as detailed in the Lloyd's Fairplay database. In 2007, there was a total of 499 cruise vessels over 100 gross tonnes (GT) in the world fleet out of a total of 74,267 vessels over 100 GT worldwide (excluding "Fishing" and "Other" vessels) (Buhaug et al., 2009). Peeters et al. (2004) stated that there were 255 cruise vessels "sailing the oceans" in 2004.

There has been extremely limited research to date into emissions factors for individual sectors of the maritime transport industry, such as calculating carbon emissions per passenger-kilometre (p-km) for cruise ships. This paper presents the first comprehensive quantitative case study for cruise ships travelling to and from New Zealand, including deriving a CO_2 emissions factor. Although information exists that cruising is a highly carbon intensive activity, currently in the general public internationally there seems to be little recognition that this is the case. In contrast, however, aviation is currently recognised internationally in the scientific community and general public as being a carbon intensive activity. The misconception concerning the carbon impact of travelling by cruise vessel may arise due to the shipping of international cargo, where it is widely known that maritime transport is less carbon intensive than air freight. Another generality that may lead to this misconception is the 'rule of thumb' that the slower the transport mode, the less carbon intensive the activity is. The results of this paper confirm that cruises emit significantly more carbon and use more fuel per passenger-kilometre than economy class aviation.

In the paragraphs below we identify the literature currently available on quantifying the CO_2 emissions of cruise ships. Gössling (2002a) noted that calculations of energy use and CO_2 emissions per p-km for different transport modes had previously excluded cruise ships. Gössling (2002a) quoted a report published in Norwegian (Lundli and Vestby, 1999) that estimated the average energy intensity of the "steamers" of the company "Hurtigruten" as 7.2 MJ per p-km.

Based on several studies from the Netherlands and several assumptions (which are not detailed in their study), Gössling et al. (2005) estimated an emission factor of 0.07 kg of CO_2 per p-km for cruise ships. According to Gössling (pers. comm., 23 February 2009), this estimate includes energy use for all services (e.g., water treatment, food preparation, entertainment, as well as transport) onboard the cruise ship.

Outside the peer-reviewed literature, the most useful figures that we have identified are from Carnival Corporation and p.l.c. (2007). Carnival Corporation and p.l.c. is the largest cruise company in the world, owning 11 major cruise brands in 2007, which together operate 85 cruise ships – 17% of the total worldwide fleet of cruise vessels as quoted in Buhaug et al. (2009). In recent years, they have published an annual environmental management report in which they provide a table presenting estimates of the amounts of CO_2 emissions per available lower berth-kilometre. Available lower berth (ALB) is a measure of the standard capacity of a cruise ship, usually assuming two people per available cabin. The estimated carbon emissions per ALB-km for 2005, 2006 and 2007 based on the cruise ship fleet of Carnival

Corporation and p.l.c. were, respectively, 0.358, 0.349 and 0.342 kg CO_2/ALB-km. The detailed methodology used to calculate these estimates is not provided in their report.

Peeters et al. (2004) examined three different cruise vessels with passenger capacities of 1791, 364 and 2000 and obtained CO_2 emissions factors of 0.52, 0.22 and 0.16 kg CO_2 per passenger-kilometre appropriate for a '100% occupation rate'. These three values were obtained from information found on three different websites that quoted the average fuel use per day as well as the passenger capacity and average speed of each vessel.

It can be seen from the above discussions that a very wide range of estimates are provided in the academic literature and from other sources, but the details of the methodologies used to calculate these values are almost entirely absent from the public domain. Estimates of emissions factors range between 70 g CO_2 per p-km (Gössling et al., 2005) and 520 g CO_2 per p-km (Peeters et al., 2004). Clearly, depending on the cruise ship fleet surveyed, the estimates will vary significantly. For example, the Lundli and Vestby (1999) study cited in Gössling (2002a) based its estimates on one company, "Hurtigruten", whose fleet is not likely to be representative of the global cruise ship fleet, nor of the international cruise ship fleet travelling to and from New Zealand. For global calculations, the larger the fleet, the more relevant the estimates, therefore the estimates from Carnival Corporation and p.l.c. (2007) are likely to be more relevant than the value provided by smaller studies, because a wider range of companies and craft have been surveyed. Some of the companies which are part of Carnival Corporation and p.l.c. operate ships travelling to New Zealand (for example, P&O Cruises). The large range of emissions factors observed could also be due to a number of factors based on individual vessels, including: vessel size, the vessels' engines age and size, level of comfort onboard, number of crew and the services the vessel offers. Also, the level of passenger loading has the potential to change the emissions factor greatly from one cruise ship's journey to another. For example, if a cruise ship with a passenger capacity of 2000 passengers carries only 1000 passengers, the carbon emissions per passenger-kilometre on this journey would be expected to be almost twice as large in comparison to an identical journey where the same ship is loaded at 100% of its passenger capacity.

In comparison to planes, cruise ships include many additional services such as accommodation, catering and leisure facilities. Becken and Hay (2007) point out that the diesel consumed onboard cruise ships is used both for transport and to generate electricity for accommodation and services. Becken and Hay (2007) estimate, based on Gössling (2002b), that transport accounts for approximately 90% of total greenhouse gas emissions from the worldwide tourism industry, accommodation for approximately 6% and activities for approximately 4%. Becken and Hay (2007) state that the emissions from restaurants and retailers have not been considered by Gössling (2002b), but are likely to be relatively minor. A recent United Nations World Tourism Organisation, United Nations Environment Programme, and World Meteorological Organization report (UNWTO-UNEP-WMO, 2008) states that transport accounts for approximately 75% of the total estimated CO_2 emissions from international and domestic tourists, with accommodation accounting for 21% and "other activities" accounting for 4%. Becken et al. (2001) state that the average energy used per visitor night staying in a New Zealand hotel is 155 MJ. In contrast the UNWTO-UNEP-WMO (2008) report states that the global average energy use per guest night is 130 MJ for staying in hotels, with the most luxurious hotels having an energy use of 322 MJ per visitor night. These values will later be compared with results from our research.

According to Dickinson and Vladimir (2007), between a third and half of the people on board of a cruise ship are members of the crew. Therefore a significant proportion of the total energy will be used for the crew and this energy, from a commercial point of view, is part of the operating cost of the vessel. Therefore, the carbon emissions per passenger are increased significantly by the energy use of the crew onboard. In contrast, for an international plane journey the crew accounts for approximately 5% (or less) of the total number of people on board. This estimate is based on Air New Zealand's operating fleet as published on their official website (Air New Zealand, online, n.d.).

Methodology

In this section we describe the methodology used to calculate a CO_2 emissions factor in grams of CO_2 per passenger km (g CO_2 per p-km) for cruise ships travelling to and from New Zealand.

The model used to calculate the fuel use and the subsequent emissions in this study is a "bottom–up", or "activity-based" model. A bottom-up approach estimates the amount of emissions based on individual activities of ships (for example, the distances travelled by ships). Conversely a "top-down" approach would use the fuel sold to cruise ships to estimate how much carbon has been emitted. Activity-based models were compared to top-down models by Buhaug et al. (2009). The team of researchers behind that study agreed that the activity-based model provides a better representation of the actual fuel use and emissions due to bunker fuel statistics including "apparent errors and other inconsistencies that could be expected to cause under-reporting of consumption" (Buhaug et al., 2009).

Certain information needs to be obtained and analysed to allow the calculation of cruise ships emissions on a per passenger basis for New Zealand in a given year. This information is listed below, and the equations used to perform the calculations are presented before the source of each of these pieces of information is discussed in turn:

- The names/identification numbers of cruise ships that visited New Zealand in a given year;
- The origin and destination of each cruise ship journey, and therefore the distance travelled;
- The number of passengers on each ship;
- The rated power of the main and auxiliary engines of each cruise ship;
- The speed at which each cruise 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 CO_2 emissions factors for each ship while travelling;
- The maximum passenger loading of each ship.

Equations:

Calculation of the emissions of CO_2 for one journey while travelling at the average cruising speed at sea is given by Eq. (1). The first part represents the CO_2 emissions for the transportation, or propulsion task, of the vessel and the second part represents the CO_2 emissions from the auxiliary engines, which provide power for the electric demand of the vessel while at sea.

$$E_{CO_2} = \frac{D}{v} \times (\%MCR \times RP \times SFOC \times EF_{CO_2})_{ME} + \frac{D}{v} \times (\%MCR \times RP \times SFOC \times EF_{CO_2})_{AE} \quad (1)$$

where

E_{CO_2} is the total emission of CO_2 over the journey in kilograms (kg);

D is the total distance travelled on the journey in nautical miles (nm);

v is the average cruising speed of the vessel in knots (kn = nm/hr);

$\%MCR$ is the average load on the particular engine as a fraction of the total installed power of the particular engine. MCR stands for 'maximum continuous rate'.

RP is the maximum rated power of the main or auxiliary engines in kilowatts (kW);

$SFOC$ is the specific fuel-oil consumption rate of the engine in kg of fuel per kilowatt-hour of engine output (kg/kWh);

EF_{CO_2} is the emission factor for CO_2 for the fuel type used by the main or auxiliary engines in kg of CO_2 emitted per kg of fuel burnt;

subscript *ME* indicates the main engines of the vessel;

subscript *AE* indicates the auxiliary engines of the vessel.

The total CO_2 emissions emitted over all journeys is the sum of the emissions of each journey. To calculate the overall CO_2 emissions factor in grams of CO_2 per passenger km (g CO_2 per p-km), the total amount of CO_2 emissions calculated above is multiplied by 1000 to convert to grams and is then divided by the sum of each individual journey's passenger kilometres. Each of the individual journeys passenger kilometres can be found from Eq. 2 below:

$$PX = N \times D \times 1.852 \quad (2)$$

where

PX is the total passenger kilometres for the journey (p-km);

N is the number of passengers onboard the cruise vessel on the journey;

D the distance the cruise vessel travelled on the international journey in nautical miles (nm);

1.852 the conversion factor for converting nautical miles to kilometres (km/nm).

The following section provides a detailed summary of the variables need to perform the calculations.

Data sources and values derived from information in data sources:

Journey information

Data on vessel movements to calculate the emissions due to cruise ships arriving and departing from New Zealand ports was acquired from the New Zealand Customs Service (pers. comm., 5 December 2008). These data were received as a spreadsheet (86,736 data entries, in 5421 rows and 16 columns) that gave journey details from all internationally departed/bound vessels departing from/arriving to a New Zealand port in the year 2007. These data were all sourced from the 'Advance Notice of Arrival' form that all ships entering New Zealand from an overseas destination must submit before they arrive. The relevant data fields taken from this form were: the name of the vessel, IMO number, craft type, gross tonnage, last overseas port and country, first New Zealand port of call, last New Zealand port of call and the next overseas port and country, scheduled arrival and departure times, and the number of passengers aboard the ship.

This data was filtered to select only cruise vessels for the purpose of this research. Of the 84 cruise ship international journeys to and from New Zealand in 2007 for which data was provided from the New Zealand Customs Service, one journey whose destination was unknown was excluded from the calculation, leaving 83 unique international journeys by 21 different cruise ships. Nine journeys for which the number of passengers on board was not available were also excluded. In addition, four other journeys in which the number of passengers was recorded as 0 or 2 were excluded because, assuming that the data was correct but in the absence of any other information, they were considered unrepresentative of a typical journey. One further vessel, which completed two international journeys, was excluded because, upon further research, it was ascertained that this vessel was not acting as a cruise vessel on these journeys. As a result of these exclusions, 68 individual journeys by 18 different cruise ships form the basis for our calculations of carbon emissions from international cruise ships travelling to and from New Zealand.

It is important to note that the basis of the calculation only includes each cruise vessel's international journeys from the last previous overseas port to a New Zealand port and the journey from a New Zealand port to the next overseas port. Each vessel's activities while in port were excluded from the calculation of CO_2 per passenger kilometre, as were journeys that were made between New Zealand ports. Thus only the international cruise component is included.

Due to the nature of the data set, each vessel's journey could not be tracked before or after the vessel's last previous overseas port and next overseas port. However, it is assumed that cruise ship passengers recorded as entering or leaving New Zealand are only undertaking a single one-way international cruise leg voyage. Although detailed statistics are not available, survey data has indicated that in 2006/2007 41% of international cruise ship passengers on domestic legs of cruise ship journeys in New Zealand had arrived in the country by air (Tourism New Zealand, 2007). Since we are only calculating emissions associated with the international maritime transport legs of cruise ships journeys in this study, flights are not included in our calculations of the CO_2 emissions attributable to cruise ship journeys.

The New Zealand port to overseas port distances were calculated by using the Dataloy Distance Table (DDT) online calculator (Dataloy, 2009) for each of the distinct international origin / destination combinations.

Vessel Details

Information about all of the 18 vessel's main engines, auxiliary engines, cruise speed, year built and normal passenger capacity were obtained directly from Lloyd's Register–Fairplay Ltd. (2009). In addition to this data source, an extensive online search was undertaken for each of the 18 cruise vessels. Furthermore, information that was deemed to be extremely accurate was retrieved for six vessels from direct correspondence with cruise lines that currently operate each of these cruise vessels.

With the exception of the passenger capacity and cruise speed for each cruise vessel, the data obtained from online sources and/or direct correspondence with the cruise lines generally agreed with the data that was obtained from the Lloyd's Register–Fairplay Ltd. (2009). Where the data from either sources did not agree a decision was made as to which data source would be used as the input values in the model. The Lloyd's Register–Fairplay Ltd. (2009) data was used for all engine details except for two vessels for which slightly different values were provided from direct correspondence with their respective cruise companies. In contrast, data from either online sources or direct correspondence with cruise lines was used for the cruise speed and passenger capacity for most of the vessels. The Lloyd's Register–Fairplay Ltd. (2009) usually gave each cruise vessel's "service speed" as higher than their "cruise speed" found from the other sources. Similarly, the Lloyd's

Register–Fairplay Ltd. (2009) usually quoted a passenger capacity higher than the passenger capacities quoted on online sources or in correspondence with cruise line companies. The passenger capacity was given in the Lloyd's Register–Fairplay Ltd. (2009) as the total number of berths on the vessel, whereas the "Passenger Capacity" from other sources generally did not give specific details as to how it was obtained. It was assumed that the cruise speed and passenger capacity quoted by the cruise lines that operate each cruise vessel would be more accurate than the Lloyd's Register–Fairplay Ltd. (2009) values.

From the value of the passenger capacity of each vessel and the number of passengers onboard as recorded by Customs New Zealand, the passenger loading factor of each journey could be calculated. We found that of the 68 international journeys to or from New Zealand by cruise ships in 2007, four of the journeys were made with a passenger loading of 50% or less, while 22 of the journeys were made with a passenger loading of 100% or higher. Passenger loadings can be above 100% when a cruise vessel utilises some of their available upper berths as well as their available lower berths.

Cruise vessels generally have one of two configurations for their engines in providing propulsion and electric power onboard (Ericsson & Fazlagic, 2008), classified as either conventional propulsion (or motor diesel) or diesel-electric propulsion. Of the 18 cruise vessels that completed international journeys to or from New Zealand in 2007, nine were conventional propulsion vessels and nine were diesel-electric propulsion vessels. Two of the nine diesel-electric propulsion vessels also had gas turbine engines installed; these types of vessels are further classified within the general type of diesel-electric propulsion vessels as combined diesel-electric and gas turbine, or CODLAG vessels. Generally speaking, the newer and larger a vessel is, the more likely it is that the vessel has diesel-electric propulsion (Ericsson & Fazlagic, 2008). This generality was observed for these 18 vessels, where relatively new built vessels with large gross tonnages made up the nine diesel-electric vessels (the vessels were built between 1990 and 2004 and had gross tonnages between 28,000 GT and 160,000 GT). The vessels with conventional propulsion were either built before 1982 or were smaller than 27,000 GT. For the nine diesel-electric propulsion vessels, including the CODLAG vessels, an estimation of their maximum installed auxiliary engine power was obtained from subtracting the total maximum power of the propulsion unit, which is analogous to the main engine size for a conventional propulsion vessel, from the total installed generating power and adding any additional auxiliary generators (three of the diesel-electric vessels had small additional auxiliary generators).

Engine operation information and emission factors

We took the average load on the main and auxiliary engines while travelling at sea to be 75% (International Maritime Organization, 2009) and 70% (Buhaug et al., 2009) respectively. For the nine conventional propulsion cruise vessels, these numbers represent the fraction of the total installed main engine power and the fraction of the total installed auxiliary engine power used while travelling at their average cruise speed at sea. For the seven diesel-electric cruise vessels (excluding the CODLAG vessels), these numbers represent the fraction of the total installed propulsion power and the fraction of the total installed generator power minus the total installed generator power plus any additional auxiliary generators used while travelling at their average cruise speed at sea. For the two CODLAG cruise vessels, it was assumed that the cruise vessels would run their diesel generators to almost full load (90% average load factor) before running their gas turbines, as the use of gas turbines leads to more expensive running costs than that for diesel generators (Levander, n.d). Assuming that these vessels need an average generator power given by: 0.75 × (the total installed propulsion power) + 0.70 × (the total installed generator power minus the total installed propulsion power) while travelling at their average cruise speed at sea and using their diesel-electric engines to 90% capacity left a load factor on one vessel's gas turbine of 49% and 60% for the other.

The values for the specific fuel-oil consumption (SFOC) rate of each engine, except the gas turbines, were assigned values from Buhaug et al. (2009). This report gave SFOC values for the main engines in nine categories that ranged from 0.175 to 0.225 kg fuel/kWh engine output based on the engines age and maximum power output. The SFOC values for the auxiliary engines from the report were 0.220 kg fuel/kWh engine output for all auxiliary engines greater than 800 kW and 0.230 kg fuel/kWh engine output for all auxiliary engines less than 800 kW. The SFOC rate for the gas turbine engines was assigned the value of 0.290 kg fuel/kWh engine output for gas turbine engines burning marine diesel oil or marine gas oil (both fuel types resulted in the same SFOC rate) (ENTEC, 2002).

The emission factors for CO_2 used in our cruise vessels emissions model were also taken from Buhaug et al. (2009). This report gave the emissions of CO_2 as 3.13 kg CO_2/kg residual fuel oil burnt and 3.19 kg CO_2/kg marine diesel oil burnt. All engines (including auxiliary engines) were assumed to burn residual fuel oil (also known as heavy fuel oil) except for the gas turbines, which were assigned the CO_2 emissions factor for marine diesel oil (Levander, n.d.).

All these values discussed above were entered into Eqs. (1) and (2) to give the results discussed below.

Results and Discussion

For the 68 international cruise vessel journeys to or from New Zealand in 2007, the total CO_2 emissions over all journeys was 52.6 kilo-tonnes (kt) CO_2 and the total passenger kilometres was 135 million p-km. This resulted in a weighted mean emissions factor of 390 g CO_2 per p-km over all journeys. For individual journeys the emissions factors ranged from 250 to 2200 g CO_2 per p-km. The highest emission factor came from the smallest cruise vessel that visited New Zealand in 2007 which was loaded at 50% capacity on that particular journey. When this same vessel was loaded at its highest capacity (115%) on another journey its emission factor dropped to 970 g CO_2 per p-km – less than half than the maximum quoted above. This shows how important passenger loading is to the emission factor of CO_2 per p-km for cruise vessels. The vessel in question was also relatively old, and, generally speaking, the smaller and older a cruise vessel is, the higher its emission factor. The lowest emission factor of 250 g CO_2 per p-km came from the newest cruise vessel with the largest passenger capacity of all the cruise vessels that visited New Zealand in 2007, and on that particular journey the vessel was also loaded at just over 100% capacity.

Fig. 1 shows the emissions factor of CO_2 per p-km against the passenger loadings for all of the 68 journeys. Each of the 18 cruise vessels is identified by a unique symbol with different shapes and/or colours. Note that the mean of the data displayed in Fig. 2 is 630 g CO_2 per p-km, which not equal to the overall weighted mean of 390 g CO_2 per p-km because each vessel has a different overall weighting with respect to the total emissions and total passenger kilometres for all vessels (i.e. larger vessels have larger engines, and therefore emit more CO_2 per kilometre, and carry more passengers than smaller vessels and so have a larger weighting on the overall emissions factor of CO_2 per p-km). Note also that there are only 34 individual points shown in Fig. 1 because each point represents two journeys by the same cruise vessel with the same emission factor and same passenger loading. This is due to the Customs data attributing the same amount of passengers for both the inward and outward journeys to and from New Zealand for each vessel. Fig. 1 shows how the emissions factor changes with the passenger loadings. For example, take the two vessels represented by the diamonds and the points-down triangles. In both cases there is a general negative trend between passenger loadings and emissions of CO_2 per p-km. Of the 68 journeys, 58 had an emissions factor between 250 and 1000 g of CO_2 per p-km and, of the ten journeys (represented by five points in Fig. 1) that had an emissions factor above 1000 g of CO_2 per p-km, four of these journeys had passenger loadings of 55% or less.

Fig. 2 shows the mean emissions factor of CO_2 per p-km over all the journeys for each of the 18 cruise vessels against the passenger capacity of each cruise vessel. The same symbols are used as in Fig. 1. There is one obvious outlying data point in Fig. 2, the cruise vessel represented by the point-up triangle in the upper left portion of the figure. This cruise vessel had a load factor of only 55% on its two international journeys, where the mean load factor over all journeys was 87%, which helps to inflate the mean emission factor for this vessel. Without considering this outlier, a general negative relationship can be seen in Fig. 2, showing that the larger the passenger capacity of the vessel, the smaller the CO_2 emissions per passenger–kilometre.

The weighted mean emissions factor of 390 g CO_2 per p-km lies at the upper end of the values found during the literature review. However, as noted previously, there have not been a large number of studies in this area published in the peer-reviewed literature.

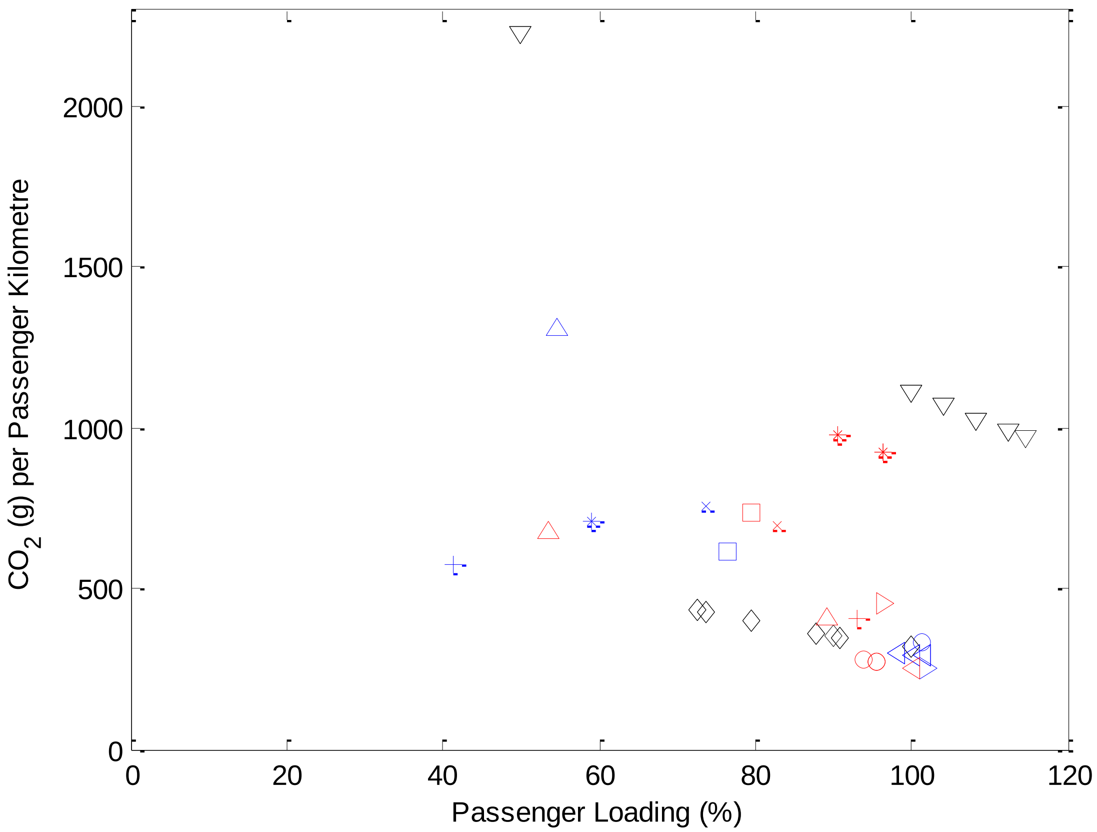

Fig. 1 – Carbon dioxide emissions in grams of CO_2 per p-km and the passenger loading for each of the 68 international journeys to or from New Zealand in 2007. Each of the 18 individual cruise vessels is represented by a unique symbol of the same shape and colour. Note: only 34 individual points are shown above because each point represents two journeys by the same cruise vessel with the same emission factor and same passenger loading.

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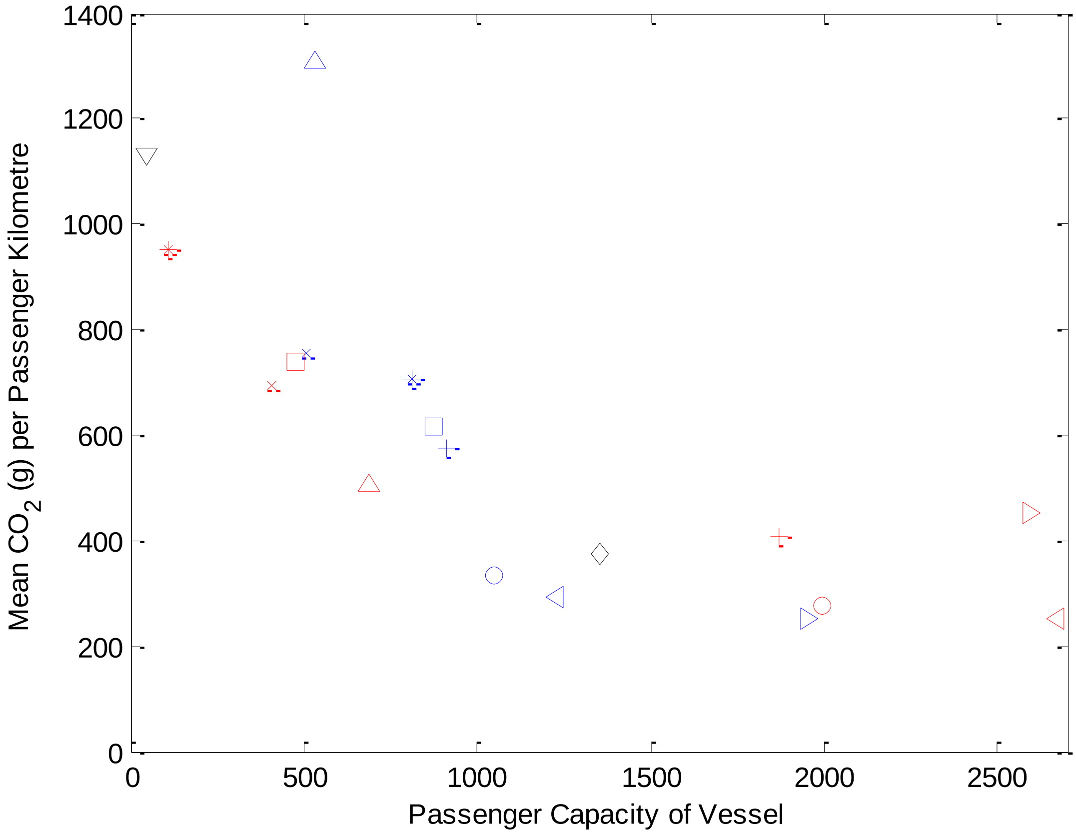

Fig. 2 – Mean carbon dioxide emissions in grams of CO_2 per p-km and the passenger capacity for each of the 18 cruise vessels that completed an international journey to or from New Zealand in 2007. Each symbol represents an individual vessel and is the same symbol that was used for each vessel in Fig. 1.

The 18 cruise vessels in this study cover a large range of gross tonnages; from 1764 to 151,400 GT, and most cruise vessels worldwide would fall within this range. These 18 cruise vessels represent about 4% of the total world cruise vessel fleet in 2007. However, 202 of the 499 cruise vessels in the total world fleet were under 2000 GT (Buhaug et al., 2009). The 17 cruise vessels in our study which are over 2000 GT represent 6% of the 2007 world fleet in this size range. Furthermore, the percentages would be higher than these if only cruise vessels that were active in 2007 were included, due to an unspecified number of cruise vessels being laid-up or not operating (Buhaug et al., 2009). The 18 cruise vessels also represent 7% of the number of active cruise vessels worldwide in 2004 (Peeters et al., 2004). Due to many cruise vessels operating in the northern and southern hemispheres during their corresponding summers, many of the vessels that visited New Zealand in 2007 can also be found operating in locations in the northern hemisphere. Therefore, the weighted mean CO_2 emissions factor of 390 g per p-km calculated in this paper may be representative of a mean emissions factor for all cruise vessels worldwide, although further research would be needed to confirm this.

By comparison, for aviation DEFRA (2008) estimates that an international plane passenger emits on average 98.3 g of CO_2 per p-km for international short haul journeys and 110.6 g of CO_2 per p-km for international long-haul journeys, where the boundary between short-haul and long-haul journeys was defined as 3700 km. The distance travelled by each of the 68 international cruise vessel journeys ranged from 1120 to 4110 km, with only two journeys over 3700 km and the mean distance travelled per journey was 2100 km. Even the estimates from DEFRA (2008) for an average long-haul first class passenger (322.8 g CO_2 per p-km) are lower than the weighted mean CO_2 emissions per passenger-kilometre calculated in this research. The UNWTO-UNEP-WMO (2008) report gives different aviation emission factors, for an EU context, of 130 g of CO_2 per p-km for air journeys between 1000 and 1500 km, 121 g of CO_2 per p-km for air journeys between 1500 and 2000 km and 111 g of CO_2 per p-km for air journeys over 2000 km. From these results, it appears that the typical cruise ship passenger emits approximately three to four times as much CO_2 per km than an economy class plane passenger. However, one needs to consider the fact that a cruise ship also assumes the function of a resort hotel and a leisure centre throughout the journey.

The auxiliary engines of a cruise vessel provide power for the electrical needs of the vessel, and by dividing the total auxiliary engines' emissions by the total emissions of the cruise vessel (main engines + auxiliary engines) an approximation for the ratio of the total emissions attributable to the "hotel" function of the cruise vessel can be made. Excluding the two CODLAG vessels, the percentage of the total emissions attributable to the hotel function of each cruise vessel was estimated as between 15% and 50%, with a per-vessel-based mean of 30%. This means that approximately two-thirds of the energy use and emissions comes from the transportation task of a cruise vessel and the remaining one-third comes from the electrical demand onboard the vessel. Multiplying the total fuel used by auxiliary engines (in kg) by the energy content of heavy fuel oil (43 MJ per kg (Ministry of

Economic Development, 2006)) and dividing by the total number of passenger nights onboard the cruise vessels gives an average energy consumption for one guest night of 1600 MJ. This value is far greater than any land-based non-moving equivalent; Becken et al. (2001) and UNWTO-UNEP-WMO (2008) gave the average energy use per visitor night staying in hotels as 155 MJ and 130 MJ, respectively. The "hotel" function of a cruise journey is still about five times higher than the average energy use for the most luxurious of hotels of 322 MJ per visitor night (UNWTO-UNEP-WMO, 2008), which would include many of the same amenities as a large cruise vessel, such as swimming pools, casinos, gymnasiums and restaurants.

Uncertainties

The dominant uncertainty in the model used in this paper to calculate the overall CO_2 emissions is the estimation of the average load on the main and auxiliary engines while at sea. The values used in this research were 75% and 70% for the main and auxiliary engines respectively. In the available literature on estimating CO_2 emissions by using an activity-based approach, the average load on the main and auxiliary engines at sea varies widely. Assuming the lowest of the values for the average load on the main and auxiliary engines at sea of 55% (Corbett and Koehler, 2003) and 30% (ENTEC, 2002) respectively leads to a weighted mean emissions factor of 240 g CO_2 emissions per p-km. In contrast, assuming the highest values for the average load on the main and auxiliary engines at sea of 80% (ENTEC, 2002; Ericsson & Fazlagic, 2008) for both leads to a weighted mean emissions factor of 430 g CO_2 emissions per p-km. Due to the unique nature of cruise vessels and their high demand for electrical power for services onboard, it is extremely unlikely that an average load on the auxiliary engines would be around the ENTEC (2002) value of 30%, which was the average value they assumed for all vessel types.

There is an uncertainty associated with the exact passenger numbers onboard each cruise vessels journey. The data received from Customs New Zealand from the 'Advanced Notice of Arrival' gives a single value for the number of passengers onboard the vessel before it arrives at a New Zealand port, and this number of passengers is assumed to be constant for the rest of the vessel's journey – including the vessel's final international journey. The passenger numbers quoted in the 'Advance Notice of Arrival' form are therefore assumed to be accurate for the first leg of the cruise vessel's journey (from an overseas port to a New Zealand port) but may not be accurate for the final leg of the cruise vessel's journey (from a New Zealand port to an overseas port). A small sample of more exact data from Customs was retrieved (Customs Staff, pers. comm., 9 November 2009) and was found to only alter the emissions factor of CO_2 per p-km by 1% for the journeys in which the small sample covered, which is insignificant when compared to the overall uncertainty.

There were other uncertainties that are not discussed here, including the actual distance travelled by each vessel and input data such as the CO_2 emissions factor per kg of fuel burnt, but these were all considered to be relatively minor.

Contextualising this research

Although passenger ships were historically important for the transport of people to and from New Zealand, international passenger travel to and from New Zealand is almost entirely carried out through aviation (over 99.5% in 2000 according to Statistics New Zealand (2000)). Smith and Rodger (2009) calculated the greenhouse gas emissions from all international aviation to and from New Zealand for the year 2005, with a total of 4.2 Mt CO_2 (mega tonnes of CO_2) emissions estimated for all international visitor air transport to and from New Zealand for that year.

The first contextual scenario considered in this research is the effect of implementing a carbon emissions price per mass unit of CO_2 emitted and considering the relative impacts on international aviation and cruise journeys, considered for transport purposes. An indicator of how much an increase in the price of a good or service would change the demand of the good is called the 'price elasticity of demand'. The price elasticity of demand, *PEQ*, is defined by Eq. 3 below

$$PEQ = \frac{\%\Delta Q}{\%\Delta P} \quad (3)$$

where

$\%\Delta Q$ is the percentage change in the quantity demanded of the good or service; and

$\%\Delta P$ is the percentage change in the price of the good or service.

The price elasticity of demand is almost always a negative number; if the price of the good or service increases (a positive percentage change in price), the quantity of the good or service demanded usually decreases (a negative percentage change in demand). There is a range of price elasticities of demand currently available in the peer reviewed literature for international leisure flights. Brons et al. (2002) give an overall mean *PEQ* for international leisure air travel of -1.146 with a standard deviation of 0.619 over 204 different elasticity values for different inputs and Njegovan (2006) states a *PEQ* of -1.3 for "tourism abroad". Outside the peer-reviewed literature, an InterVISTAS (2007) report found a range of price elasticities in their extensive literature review of -1.2 to -1.5 for a base elasticity at the route/market level. Currently, there is less available literature on the price elasticity of demand for cruising, although one study found a price elasticity of demand for cruising of "-2.0 or greater for various measures in price and for various specifications" (Coleman et al., 2003). The price elasticity of demand is greater in absolute value for cruising than for aviation, which means that cruising is more responsive (with respect to demand) to relative changes in price than aviation. Thus for the same percentage change in price in both industries, the percentage change in demand will be greater for cruising than for aviation. What follows below is a simplified hypothetical situation that looks at the impact of a carbon emissions price on an international flight and cruise journey.

As of 1 July 2010 the transport sector enters into the New Zealand Emissions Trading Scheme (ETS). After two and a half years, once "progressive obligation" has been phased out, the price of CO_2 emissions will be $NZ25/tonne of carbon dioxide equivalent (Ministry for the Environment, 2009). We will therefore consider a scenario in which a carbon price of this amount was set internationally, and quantify the effect on a single journey between Sydney and Auckland by plane and by cruise. Dataloy (2009) gives the distance for a vessel travelling between Sydney and Auckland of 1287 nm (2384 km) and the great circle path distance, multiplied by 1.09 to account for indirect routes and circling at airports (DEFRA, 2008), for a flight between Sydney and Auckland is 2357.4 km. Note that the distance the cruise vessel has to travel is only 26.6 km further than the aircraft in this example due to the journey being relatively unobstructed by land; the difference in distances, and therefore emissions, would be far greater for journeys in which major landmasses are flown over by the aircraft. One passenger on a cruise vessel would therefore typically produce about 930 kg of CO_2 on the journey between Sydney and Auckland, using the emission factor from this research of 390 g of CO_2 per p-km. In contrast, one passenger on a plane would typically produce about 230 kg of CO_2, using the short-haul international emission factor of 98.3 g of CO_2 per p-km

(DEFRA, 2008). Assuming a carbon price of $NZ25 per tonne of CO_2, there would be an extra cost of $NZ23.25 for the passenger on the cruise and $NZ5.75 for the passenger on the plane. The cost of a one-way, 4 night cruise from Sydney to Auckland was found online from a cruise line to be $NZ457 pp (including taxes) for the cheapest option; which consisted of four people occupying a 17 m^2 cabin. The cost of a one-way flight from Sydney to Auckland was found online from an airline to be $NZ316 pp (including taxes) for the cheapest available option. The relative price increase per passenger from the implementation of this carbon pricing would therefore be about 5% for a cruise passenger and 2% for an aircraft passenger. Using a price elasticity of demand of -2.0 for international cruising and -1.3 for international leisure air travel, these relative price increases would see a drop in demand by about 10% for international cruises and 2.6% for international air travel. While these numbers are presented as indicative values only, they do illustrate the fact that the international cruise industry would be more affected by the implementation of carbon emissions pricing than the international aviation industry.

A second and final contextual application of this research is a case study on a cruise vessel and its potential to reduce its CO_2 emission factor per passenger kilometre. We selected a vessel for this case study that had detailed information available on its deck plans as well as having a mean emissions factor that was at the lower end of the range, so that any reduction of emissions is therefore a "best case" scenario. This vessel had the fourth largest passenger capacity of the 18 cruise vessels with a mean emissions factor of 250 g CO_2 per p-km and had 1011 double lower berth cabins in total. The majority (973) of the double berth cabins were between 135 and 179 square feet in size (1 square foot = 0.0929 square metres), 32 were between 370 and 536 square feet and 6 were between 538 and 695 square feet.

This particular vessel also includes many public areas, including: boutique shops, a medical centre, dinning rooms and bars, library, two theatres, casino, gym, swimming pool and spas and a youth centre. In order to calculate how much the emission factor of CO_2 per p-km could be reduced by increasing the passenger capacity, the following assumptions were made: all accommodation units were resized to be 135 – 148 square feet containing four berths (two sets of double bunk beds). In addition, the two theatres, the library, lounges and three bars occupying one whole deck of the vessel were converted into accommodation units. Finally, on other decks, the casino, some bars, the boutique shops, patisserie and the grand plaza were also transformed into accommodation units. The remaining facilities (e.g. medical centre, dining rooms and outdoor areas) were all kept unchanged. These hypothetical alterations increased the capacity of the cruise vessel from 2022 lower berths to 6930 lower and upper berths. If the total CO_2 emissions from a journey by this vessel with these alterations was the same as calculated previously and the vessel was loaded at its new capacity (6930 passengers), then the emissions factor would be reduced from 250 g CO_2 per p-km to 72 g CO_2 per p-km. Once again, this value is presented as an indicative value only. In practise, it is likely that the total CO_2 emissions would increase in this new, hypothetical cruise vessel due to the electrical demand onboard being higher. For example, consider the extra energy that would be needed to provide fresh, hot water for showers plus food storage and preparation for over three times the amount of passengers. It is also recognised that these alterations may not be feasible in real life due to safety measures not being taken into account (for example, the number of lifeboats would have to also be greatly increased) as well as the increased number of crew and crew facilities not being included. This simple renovation model cannot account for these differences; however the example above does provide insight into how the emissions per passenger kilometre could be reduced heavily by the sacrifice of some luxury amenities and by maximising the available accommodation space. From the above example it can be inferred that it is theoretically possible that the emissions factor of CO_2 per p-km for a large cruise vessel could be comparable to that of economy class aviation (between 98.3 g CO_2 per p-km (DEFRA, 2008) and 130 g CO_2 per p-km (UNWTO-UNEP-WMO, 2008)) if passengers are accommodated more tightly and some luxury amenities are dispensed with.

In the current study, 68 international cruise journeys carried a total of 59,636 passengers in the 2007 calendar year and generated an estimated total of 52.6 kt CO_2 emissions. Cruise vessels dock at several New Zealand ports and stay in each port generally between 10 and 12 hours (Tourism New Zealand, 2007). The mean length of time each passenger stayed in New Zealand was 8.8 days and the mean number of shore excursions per passenger-visit was 6.4 (Tourism New Zealand, 2007). These shore excursions generate revenue in New Zealand due to the cruise passengers' spending. A survey of 340 cruise passengers from five different cruise vessels which docked in Auckland in 2009 indicated that the mean expenditure per person on a cruise journey in New Zealand is between $NZ200 - $NZ500 (Auckland Regional Council, 2009). Assuming that each cruise passenger spent an amount within this range while in New Zealand for the year 2007, estimated revenue of between $NZ12 million and $NZ30 million was generated. A separate report that used 1997 expenditure figures and economic projection models based on actual passenger numbers estimated the total cruise passenger expenditure as $NZ86.2 million with a mean of $NZ741 per passenger for the 2007/08 season (Cruise New Zealand, 2008). The revenue from international cruise ship passengers is important to the New Zealand economy, but is small compared to the total tourism expenditure of $NZ20.4 billion for the year ended March 2007 (Statistics New Zealand, 2009). The total CO_2 emissions from international cruise ship journeys to

New Zealand are about 80 times smaller than the total CO_2 emissions from international visitor aviation journeys estimated by Smith and Rodger (2009). Both international cruises and international aviation would not be affected by the present New Zealand national emissions trading scheme because international transport is currently excluded. However, there is a possibility that international transport would be accountable in some way in the future after the Kyoto Protocol expires. Any future New Zealand or international policy measure that aims to decrease international passenger transport emissions would need to be carefully constructed so that there are not perverse incentives that could inadvertently promote more carbon-intensive activities such as cruise ship journeys in their present form. Without the implementation of new policy measures, it seems unlikely that the industry would implement changes such as the example considered above of reducing the space and luxury amenities in order to reduce the carbon dioxide emissions per passenger kilometre for cruise ships.

Summary and Conclusions

An activity-based, or "bottom-up", approach was used to calculate the emissions resulting from international cruise vessel journeys to and from New Zealand. Data was obtained from the New Zealand Customs Service for all international cruise vessel arrivals and departures for vessels that called at New Zealand ports during 2007. The distances travelled between each New Zealand port and each corresponding overseas port were obtained from the Dataloy Distance Table, an online maritime distance calculator. The size of the main and auxiliary engines, year built, cruise speed and passenger capacity for all of the cruise vessels were obtained from a combination of Lloyd's Register–Fairplay Ltd. (2009), some online sources and also direct communication with some of the cruise lines. The average loads on the main and auxiliary engines were approximated by values from Buhaug et al. (2009) and International Maritime Organization (2009) respectively. CO_2 emissions factors and specific fuel-oil consumption rates were also obtained from Buhaug et al. (2009). From these inputs, a weighted mean value for the CO_2 emissions per passenger kilometre for cruise vessels completing an international journey to or from New Zealand in 2007 was found to be 390 g CO_2 per p-km, with a range of between 250 and 2,200 g CO_2 per p-km for individual journeys. There were some limitations in the data that was collected and in the methodology of the calculation, with the dominant uncertainty being estimating the average load on the main and auxiliary engines. Data from Customs only provided journeys to/from the first/last previous overseas port from/to the New Zealand port of origin/departure only, and so the emissions that were calculated may not represent the emissions related to longer journeys.

The emission factor of 390 g CO_2 per p-km was found to be approximately three to four times higher than the emissions factors relating to international aviation, and therefore cruising was confirmed to be a more carbon intensive mode of international transport than aviation. Using a simple price elasticities calculation, the relative decrease in demand for international cruising was seen to be larger than that for international aviation when a price increase due to the introduction of carbon pricing was assumed. Finally, a case study of a representative cruise vessel was examined for how its passenger capacity could possibly be increased, and therefore decrease its overall emissions factor of CO_2 per p-km. It was shown that with the highest theoretical passenger capacity of the cruise vessel, its emissions factor could possibly be comparable to an emissions factor for economy-class international aviation.

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