WESTERN NORWAY RESEARCH INSTITUTE
VESTLANDSFORSKING
www.vestforsk.no

Vestlandsforsking-note nr. 2/2011

Energy use and CO_2 emissions from cruise ships — A discussion of methodological issues

Hans Jakob Walnum

Vestlandsforsking, Pb 163, 6851 Sogndal • Tlf.: 906 33 600 • Faks: 947 63 727

Vestlandsforsking note

Title Energy use and CO_2 emission from cruise ships — A discussion of methodological issues.	**Note number** 2/2011 **Date** 09.03.2011 **Grading** Open
Name of project Sustainable Destination Norway 2025.	**No pages** 26 **Project nr.** 6124
Researcher(s) Hans Jakob Walnum	**Project leader** Stefan Gössling
Contractor .Minister of trade and industry	**Key Words** Cruise tourism Energy use CO_2 emissions
ISBN: xx-xxx-xxxx-x	**Pris:** xxx kroner

Contents

List of figures

List of tables

Introduction

Cruise ship tourism constitutes the most energy intense form of tourism on a per tourist basis (Eijgelaar et al. 2010). The International Maritime Organization (IMO) estimated that in 2007 the global fuel consumption of passenger ferries and cruise ships was 31.3 million tonnes (Mt), which corresponded to an approximate production of 96 Mt carbon dioxide (CO_2). This represents 9.2% of the total emissions from global shipping (Buhaug et al. 2009), of which global shipping accounts for 3.3 % of global CO_2 emissions (Gössling 2011). Cruise ship tourism has largely been excluded from the climate mitigation debate because it is still a relatively small sector within the tourism industry. However, it is the fastest growing type of tourism worldwide, with an annual growth rate of 7.4% since 1990 (Eijgelaar et al. 2010). Therefore, knowledge about the energy used by this industry and its resulting CO_2 emissions is important.

Until recently, energy use by cruise ship tourism and its CO_2 emissions were unknown; however, publications in the form of peer-reviewed literature (Eijgelaar 2010, Howitt et al. 2010) and environmental reports from cruise companies, as well as a Web calculator (www.atmosfair.de/en/act-now/contribute-now/kreuzfahrt/), now provide information about CO_2 emissions and energy use. This paper draws upon this work and highlights methodological issues in calculating these values.

We will discuss the following issues:
1) Energy use by cruise ships and their CO_2 emissions as compared to other forms of passenger transport on the basis of emissions per passenger–kilometre (p–km). A passenger–kilometre represents one passenger transported 1 kilometre (km). The number of passenger–kilometres is defined as the distance a transport travels multiplied by the number of passengers in transport.
2) Energy use by cruise ship tourism as compared to other forms of tourism on the basis of the aggregated energy use per passenger–day.
3) The volume of CO_2 emissions from cruises in Norway as determined by a preliminary calculation. We define a Norwegian cruise as transport of foreigners by a cruise ship where Norwegian harbours are the destination.[1] We calculated the energy use by 28 cruise ships that went to Norway in 2010 and their CO_2 emissions.
4) Overarching strategies for curbing emissions from cruise ship tourism, including the efficiency approach (technological improvements in energy efficiency and emissions reduction), the substitution route (switching to more environmental benign forms of travel), and the reduction approach (reducing the total travel or transport distances).

Former studies

Carnival Corporation calculates CO_2 emissions directly from their fuel use, and expresses it in terms of available lower berth (ALB) kilometres. In 2008, Carnival carried 8,183,000 passengers, with an ALB occupancy rate of

[1] The number of passengers is obtained from the Norwegian foreign travel survey (Rideng and Farstad 2009). This survey did not include Norwegians onboard the cruise ships; however, this was not expected to play an important role in the total number of travellers (personal communication).

105.7%.[2] Carnival primarily uses heavy fuel oil (HFO), with a calculated CO_2 emissions value of 3,117 kg/t. Their ships also use marine diesel oil (MDO), with a calculated CO_2 value of 3,082 kg/t, and marine gasoline oil (MGO), with a calculated CO_2 value of 3,127 kg/t. Together, the amount of MDO and MGO comprises 4% of the company's total fuel use. In 2008, an estimated 0.1148 fuel/ALB–km was used and 0.330 kg CO_2/ALB–km was generated (Carnival Corporation 2009a, Carnival Corporation 2009b). We emphasise, however, that the ALB is based on accommodation capacity. It does not consider actual load factors, so the CO_2 emissions per passenger–day or passenger–kilometre can be higher or lower than the ALB suggests.

The Royal Caribbean Cruise Line (RCCL) provides information about fuel use relative to the available passenger cruise days (APCD). APCD is their measurement of capacity and represents double occupancy per cabin, multiplied by the number of cruise days for the period. In 2008, they had an occupancy rate of 104.5%. On the basis of the on board fuel consumption, 60% of the energy use should be allocated for the ship propulsion, which increases to 73% if the "engine room and auxiliary equipment" is included. According to RCCL, their 2008 greenhouse gas footprint was 0.14466 Mt of CO_2 per APCD, including refrigeration losses. The total CO_2 emissions without refrigeration losses were 3,679,578 Mt, or 0.13904 Mt per APCD (Royal Caribbean Cruises 2009).

Eijgelaar et al. (2009) related the number of cruise passengers given by Mintel (2008) to fuel consumption given by the IMO (Buhaug et al. 2009). They found that 6.12 Mt of fuel was attributed to cruise ships. Applying the CO_2 emissions factors for HFO and MDO to fuel consumption of gives 19.17 Mt CO_2 for all cruise ships in 2007. With 16 million cruise passengers in 2007 (Mintel 2008), the average passenger generated approximately 1.2 t CO_2 per trip. The average cruise length in 2007 was 7.1 days (CLIA 2009), so the average emissions per passenger per day is estimated at 169 kg CO_2.

Howitt et al. (2010) calculated the CO_2 emissions of international cruise ship journeys to and from New Zealand in 2007, using an activity-based, or a ''bottom-up'', model[3]. Lloyd's Register - Fairplay Ltd. (2009) was used to find the size of the main and auxiliary engines, year built, cruise speed and passenger capacity for the cruise vessels. This information was then combined with information from online sources and direct communication with the cruise lines. They found that emissions from individual journeys by cruise ships to or from New Zealand ranged between 250 and 2200 grams of CO_2 per passenger–kilometre (g CO_2 per p–km), with an average of 650 g CO_2 per p–km and a weighted mean of 390 g of CO_2 per p–km. The weighted mean is less than the mean because it considers the total kilometres travelled by passengers, and larger ships carry more passengers and are therefore more energy efficient on a per kilometre scale. Another interesting finding was the energy use per passenger night for the ''hotel'' function of these cruise vessels was 1600 MJ per visitor night, which was 12 times larger than the value for a land-based hotel. They assumed that approximately two-thirds of the energy use by a cruise vessel and the resulting CO_2 emissions were from the transportation task, and the remaining one-third was from the electrical demand onboard the vessel; this is similar to that found by RCCL.

---

[2] The occupancy rate can be greater than 100% because some cabins can accommodate three or more passengers, and the ALB is based on two passengers per cabin.

[3] The methodology was based on the following variables:

- The names and identification numbers of cruise ships that visited New Zealand in 2007
- 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 ship; and
- 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 emission factors for each ship while travelling
- The maximum passenger loading of each ship

Atmosfair (https://www.atmosfair.de/en/act-now/contribute-now/kreuzfahrt/), a German non-profit environmental organisation, has developed an online calculator that determines the CO_2 emissions that are created when a person travels by cruise ship. The amount of CO_2 created by a journey by cruise ship is calculated from the following data:

1. The number, type, manufacturer, consumption, and performance of all motors, generators, and power units for the propeller. Data on the manoeuvring thrusters (bow thrusters and so on), the type of drive (diesel or gas turbine), and the number of engines and their power are included if known.
2. The number of passengers on each cruise vessel.
3. The number, size, and category of all cabins of the ship.

The CO_2 emissions calculator has a database of 210 cruise ships from 37 shipping companies. The calculator differentiates between six categories of cruise ships depending on their size and differences in terms of comfort, features, and concept.

The Carbon War Room (www.carbonwarroom.com/battle/shipping) has applied the methodology of the United Nations Energy Efficiency Design Index (EEDI) to develop ratings for over 390 cruise vessels. The EEDI is a measure of energy use and the corresponding greenhouse gas emissions of ships. These ratings are available on the ShippingEfficiency.org Web site.

Each study or organization expresses CO_2 values differently, and the values are not comparable. To make them comparable, we will normalise each source to "emissions per passenger–kilometre". Ideally, that number should reflect the actual number of passengers carried, distances travelled, and fuel used. This factor will also vary depending on time spent in different operating modes—how much time is spent cruising, manoeuvring, and in port.

To convert estimates made by Eijgelaar, Atmosfair, and RCCL into passenger–kilometres (p–km), we use information from Carnival Corporation (2009a, 2009b) that states that the company had 8,183 million passengers for the year in which the emissions were 0.330 per ALB–km. With an occupancy rate of 105.7%, this corresponds to 312.2 g CO_2 per p–km. Using information on Carnival's fuel use, we find that each passenger has a CO_2 emissions of 1.21 tonnes per journey. If we divide this by 7.1 (the world average number of cruise days per passenger), this equals 170 kg per passenger–day. To find the travel distance per passenger–day, we divide 170 kg by 312.2 g CO_2 per p–km, which gives 544.5 km.

Table 1 *CO_2 emissions per passenger and per passenger–kilometre*

Source	CO_2 emissions	CO_2 emissions (g per p–km)
Carnival 2008	0.330 kg CO_2 per ALB–km	312
RCCL 2008	139 kg per APCD	244
Eijgelaar et al. 2010	169 kg per passenger–day	310
Howitt et al. 2010	0.250–2.200 kg of CO_2 per p–km	250–2,200
Atmosfair 2010	248–740 kg CO_2 per day sailing	456–1,359
Shipping Efficiency 2011	Only rating A–G	Not possible

Methodological issues

In this section, we discuss some key methodological questions connected to the estimation of energy use by cruise ships and the resulting CO_2 emissions.

We can distinguish between two approaches of calculating ship emissions. The first calculates fuel use and CO_2 emissions using a top-down approach, which is based on the aggregate level of fuel sold. The second calculates emissions using an activity-based or bottom-up approach. This method calculates fuel use and emissions on the basis of engine loads, along with information on sailing times and emissions factors. Buhaug et al. (2008) discussed the applicability of these two approaches. They found that the activity-based model provided better projections of global fuel consumption by international shipping and the resulting CO_2 emissions because of problems in accurately reporting marine bunker sales.

Both approaches can be used when looking at energy consumption and CO_2 emissions in a life cycle perspective that involves the following:

A) **The direct energy use (and emissions)** is the energy required for propulsion of the cruise ship.
B) **The gross direct energy use (and emissions)** considers the energy used in the system for production and distribution (for example, transmission loss) of the energy carrier (fuel) up to the point of its final use.
C) **Indirect energy use (and emissions)** is the energy required to build, maintain, and dispose of the infrastructure, as well as the means of fuel transport.

Direct emissions from ships

Direct emissions are emissions produced by the cruise ship itself and include those generated from moving the ship as well as those generated from powering the ship's onboard facilities and systems. The top-down approach calculates fuel use and CO_2 emissions using the aggregate level of fuel sold. The direct energy use and CO_2 emissions can be calculated through a direct knowledge of fuel consumption:

- World aggregated level of fuel use
- Total fuel used by a company
- Daily consumption of fuel for a specific ship

We must know the type of fuel and its energy density and its emissions values to calculate energy use and emissions.

Royal Caribbean Cruises (2009) and Carnival Corporation (2009) use the top-down approach to determine their CO_2 emissions. Their fuel consumption is multiplied by an emission factor, which is dependent on the type of fuel.

On the other hand, the activity-based model calculates emissions on the basis of the main and auxiliary engine capacity (Maeset et al. 2007, Buhaug et al. 2008). In this approach, information about the following parameters is required:

- Capacity and type of engine (including both the main and the auxiliary engine),
- Age of engines,
- Load on main and auxiliary engine, and
- The amount of time spent in different operating modes—cruising, manoeuvring, and in port.

Eijgelaar et al. (2010) used this approach to determine the aggregate level of fuel use by the cruise industry.

Howitt et al. (2010) also calculated CO_2 emissions from information on the main and auxiliary engines in their New Zealand case study; however, they only considered the sailing to and from New Zealand and did not account for the time spent sailing between New Zealand ports or for the time spent in port. Atmosfair has also calculated CO_2 emissions on the basis of the main and auxiliary engines. In addition, they differentiated between the time spent in port and time spent at sea.

A third way to calculate emissions is to estimate fuel use on the basis of gross tonnage and type of ship (Trozzi and Vaccaro 1998), which was recommended by the Intergovernmental Panel on Climate Change (IPCC 2006). Trozzi and Vaccaro (1998) suggested a linear regression analysis, and calculated the fuel use (C) of a passenger ship with the following formula: $C = 16.904 + .00198 * GT$, where GT is the gross tonnage of the ship.

Apart from the calculation methods, other variables will also have a critical influence on the direct energy used by cruise ships and the resulting emissions. For example, the type of fuel has an influence. The global cruise fleet uses HFO (Eigjelaar 2010), HFO can have different CO_2 emission values in kilogram per kilo of HFO consumption depending on its carbon content—3.02 (Buhaug et al. 2008), 3.117 (Carnival 2009), and 3.13 (Buhaug et al. 2009). VTT (the Technical Research Centre of Finland) uses a value[4]. of 3.118 Levels of MDO are also different, ranging from 3.19 (Buhaug et al. 2009) to 3.127 (Carnival 2009).

When expressing energy use and CO_2 emissions per passenger–kilometre or passenger–day, the level of passenger loading has the potential to change the emissions factor greatly from one cruise ship's journey to another. We also need to know the distances travelled to find emissions per passenger–kilometre. Another challenge is how to compare cruise ships to other forms of tourism because a cruise ship can serve as both a hotel and a mode of transport.

Gross direct emissions

The previous studies did not look at the full life cycle of the fuel. To calculate emissions from well to tank or the gross direct emissions, we use data from Ecoinvent. The Ecoinvent database (Spielman et al. 2007) includes the gross direct energy—all energy losses and emissions in the production, conversion, and distribution of energy—from a model of HFO in regional storage. The gross direct energy chain of a cruise ship would then consist of the energy used in the following processes:

1. Extraction/production of the energy source;
2. Transportation of the energy source;
3. Production of the energy carrier (fuel, electricity);
4. Distribution of the energy carrier;
5. Propulsion and accommodation needs (direct energy use) of the cruise ship.

The first four are additional inputs—the energy needed to produce the fuel. The fifth item is direct energy use (Høyer and Heiberg1993). We calculate the gross direct emissions from Ecoinvent as being the difference between CO_2 emission from operating a "transoceanic tanker" and "HFO at regional storage/RER". Using this calculation, we find that the CO_2 emissions value must be multiplied by 1.13to include the emissions from the extraction and production of HFO[5] . We only present values for HFO since this is the most commonly used fuel.

[4] VTT applies this factor for ships in the Baltic Sea. The Baltic Sea is in a SO_x Emission Control Area (SECA) and the sulphur content in the fuel is regulated.

[5] In transoceanic tanker operations, an amount of 0.0013 HFO equals a CO_2 emission of 0.00454 kg. 1 kg of HFO at regional storage yields CO_2 emissions of 0.402 kg. This implies that 11.5% could be ascribed to the extraction and distribution phase or a multiplication factor of 1.13.

Indirect emissions from ships

Ideally, we should also know the energy used and the emissions produced during the construction, maintenance, and operation of the cruise ship infrastructure—the harbours and that of the ship itself. Ecoinvent (Spielman et al. 2007) included manufacturing and maintaining the ship, as well as disposing of motor vehicles and parts for the ships. Infrastructure is also included and addresses the construction, operation, and disposal of the transport infrastructure. According to Ecoinvent, a “transoceanic tanker” generates 83% of its total life cycle CO_2 emissions from operation of the ship; 15.07% from port operation; and 2% from the production, 0.01% from the maintenance, and 0.01% from the construction of port facilities. Simonsen (2010) estimated the total CO_2 emissions from various freight ships, and found that the port infrastructure and the building of ships played a minor role. The CO_2 emissions generated from these two processes varied from 2.7% for an LNG (liquefied Natural Gas) tanker with a deadweight of 200,000 tonnes to 11.3% for an LPG (liquefied petroleum gas) tanker with a deadweight of 200,000 tonnes.

Previous research allocated a percentage of port infrastructure on the basis of a ship’s freight in tonnes, and the numbers for infrastructure processes were obtained for the harbours in Rotterdam and Hamburg. Although it would be relevant to include infrastructure for cruise ships, we cannot make this calculation because of the following reasons:
1) Figures for passenger terminals are not available.
2) Allocating quay structures between ships that carry passengers and ships that transport freight is difficult.
3) The size and function of international harbours (as used in Ecoinvent) and Norwegian harbours are significantly different.

We expect the energy use for the infrastructure part to be insignificant compared to the propulsion of the boat. The picture could be different for harbours that are constructed only for cruise ships and for those harbours that have needed improvements to be able to handle cruise ships, but in a worldwide and Norwegian context, we expect that this will play a minor role.

Theoretically, it seems easier to do calculations on ship building that are based on material consumption and expected lifetime performance. This is not done in this report because of a lack of data as well as the inability to obtain information connected to the building of cruise ships. Although newer and larger cruise ships are believed to be more energy efficient, more energy may be required during construction; however, this hypothesis has been impossible to check since information about energy use and the emissions connected to the production of cruise ships is not available.

Additional travels for cruise tourism

In the previous sections, we discussed the energy chains for cruise ships. Cruise tourism, however, has an additional component to the energy chain that can be environmentally problematic, as highlighted by Eijgelaar et al. (2010). They reported that cruise emissions consist of not only the emissions from the cruise ship itself, but also the emissions from the mode of transport (usually planes) used by the tourists to travel from and back to their homes to the port of embarkation and disembarkation.

Quantifying the amount of additional travelling in the cruise industry is challenging. Information about the nationalities of the passengers and their point of departure for a cruise is not collected—for example, how many

Americans travel to England before they start their cruise. If this information is estimated, a substantial uncertainty will remain as to the accuracy of the result. However, this travel to and from the point of departure involves a considerable amount of CO_2 emissions. In 2005, for instance, Norway had 90,000 cruise passengers from the United Kingdom, 89,000 from Germany, 61,000 from Canada and the United States, 14,000 from Spain, 20,000 from Italy, 8,000 from France and 42,000 from other countries. Americans and Canadians will probably travel by plane to London; Italians and Spaniards by plane to London, Hamburg, Amsterdam, or another destination; and Germans and French by car, train, or bus to their point of departure. The additional travel could be very influential for long intercontinental flights. For example, if we assume a population-weighted average of U.S. airports, then this corresponds to a flying distance of about 7000 km for Americans travelling by plane from the United States to England. If we apply an emissions factor for long haul flights of 105.5 g CO_2 per p–km (DEFRA 2008) and consider the contribution of condensation trails and the contribution from cirrus (http://www.cicero.uio.no/fulltext/index.aspx?id=5903&lang=no) by using a multiplication factor of 1.8 for CO_2, then the direct CO_2 emissions for the additional travel to and from the United States to England will be 2658.6 kg of CO_2. On a per journey basis, the additional travel could be the most significant portion of the total CO_2 emissions. For a one-week Mediterranean cruise which starts and ends in Barcelona, we estimate that the total emissions is 2.087 t of CO_2, and the travel by plane was 48.5% of that total. For a Caribbean cruise with the same cruise ship, the additional travel by plane will have a larger impact and will represent 69.8% of the total CO_2 emissions from this cruise of 4.146 t. See Appendix 1 for detailed information on how the estimates were made for the Mediterranean and the Caribbean cruises.

Calculations of direct emissions from cruise ships

We calculated the direct emissions for 28 ships that arrived in Bergen in 2010. A total of 78 cruise ships arrived in Bergen from March to September (Bergen Harbour Department). Cruise ships have several calls to the same destination, and our case study represents 55.6% of the calls to Bergen and 57% of the cruise passengers arriving in Bergen during that period, or 161,043 of a total 291,887 passengers.

The most precise way to calculate energy use and CO_2 emissions is by using the actual fuel consumption for a specific cruise. However, this data is not available. Instead, we obtained fuel consumption data from Sea-web (www.sea-web.com), the online database maintained by Lloyd's Register - Fairplay. Our selection of ships was based on whether or not information on the daily fuel consumption was available in the cruise ship database. Daily fuel consumption is given in tonnes by the owners or managers for ships or by other parties, such as the industry itself. The given fuel consumption is for normal service operation at sea. The speed is usually the normal service speed; in some instances, however, consumption is given for an “economic” operating speed. Data for fuel use while in harbour is not included in their statistics (personal communication). We will not provide ship names in this study because of the confidential issues related to using the database.

The amount of time spent sailing, the amount of time spent in the harbour, and the total distances sailed are needed to calculate the emissions. We assumed that an average of 7 hours was spent docking and that the average distance sailed per day was 468 km. The amount of time spent in the harbour and sailing distances were culled from 10 planned Norwegian cruises in 2011, which listed Bergen on their itinerary. We assumed that the ship’s hotel function operated when the ships were in harbour, and that this function represented 30% of the total operating power (Howitt et al. 2010, Royal Caribbean Cruises Ltd. 2009). We used actual passenger numbers and the average number of passengers for ships with several port of calls to Bergen. We used a CO_2 emissions value of 3.13 to convert HFO consumption into a CO_2 emissions value. This is the same value for HFO used by Howitt et al., Eigjelaar et al., and Buhaug et al. (2009). We placed the cruise ships in five categories, A–E, according to their GT. This is the same categorisation used by Buhaug et al. (2008 p. 31).

Table 2 *Number of cruise ships and the percentage of total passengers in the different cruise ship categories*

Category	Size in GT	Number of cruise ships in the case study	Number of cruise ships arriving in Bergen in 2010	Percentage of passengers
A	100,000 +	1	6	This ship carried 11% of the passengers in our case study. This ship category carried 19% of the cruise passengers that arrived in Bergen in 2010.
B	60,000–99,999	5	16	These ships carried 44.5% of the passengers in our case study. This ship category carried 41.7% of the cruise passengers that arrived in Bergen in 2010
C	10,000–59,999	17	41	These ships carried 42.5% of the passengers in our case study. This ship category carried 37.7% of the passengers that arrived in Bergen in 2010.
D	2,000–9,999	4	14	These ships carried 1.9% of the passengers in our case study. The ship category stood carried 1.6% of the passengers that arrived in Bergen in 2010.
E	–1,999	0	1	This category is not included in our sample of ships. Only 46 passengers arrived in Bergen on a ship in this category in 2010.

Our selection criteria (only ships with information about fuel consumption were included for our study) gave us a limited sample of sailing distances and assumption about the amount of time spent sailing and in harbour, the number of ships and the slight bias in our sample i.e. we have only one ship in category A, implies that our study is not representative of all ships arriving in Bergen and Norway in 2010.

Table 3 *Direct CO_2 emissions from cruise ships per passenger–day and per passenger–kilometre*

Ship number	Ship category	kg CO_2 per passenger–day	g CO_2 per passenger–kilometre	ALB[6] occupancy rate (%)
1	A	93.0	198.8	108.4
2	B	200.1	427.5	112.4
3	B	185.2	395.7	107.1
4	B	214.3	458.0	109.4
5	B	243.6	520.5	101.0
6	B	260.2	556.0	105.5
7	C	368.8	788.2	64.5
8	C	202.3	432.2	91.3
9	C	214.0	457.3	94.6
10	C	227.6	486.2	97.7
11	C	170.0	363.2	90.5
12	C	231.9	495.4	65.8
13	C	434.3	928.1	69.7
14	C	236.6	505.5	92.9
15	C	173.5	370.8	84.0
16	C	336.3	718.5	96.4
17	C	201.2	429.8	105.8
18	C	235.1	502.3	97.1
19	C	115.7	247.3	108.9
20	C	348.2	745.3	86.0
21	C	246.5	526.3	93.6
22	C	227.2	485.5	84.6
23	C	615.7	1,314.5	60.0
24	D	93.9	200.7	78.0
25	D	134.1	286.6	102.6
26	D	338.4	723.0	61.7
27	D	337.9	722.8	87.2
28	D	392.8	838.2	102.4

Our estimates are in line with previous estimates (Howitt et al. 2009, Atmosfair 2011) and highlight the large differences in CO_2 emissions between individual cruise ships. Emissions range from a minimum of 93 to a maximum of 615.7 kg CO_2 per p–day, or from 198.8 to 1,314.5 g CO_2 per p–km. The largest ship in the case study has the lowest direct CO_2 consumption. This could be explained by the high occupancy rate (almost 3000 passengers), and the age of the ship (less than 10 years old).

More surprising is the relatively high CO_2 consumption per passenger for ships in category B. Three of the cruise ships in this category have a CO_2 emissions value below 500 g CO_2 per p–km. These are relatively new ships, less than 5 years old. They are also large ships that carry between 2300 and 2800 passengers on average. The ships with an emissions value above 500 g CO_2 per p–km were between 10 and 15 years old and carried between 1750 and 2100 passengers. A possible explanation for the relatively high CO_2 emissions for ships in category B could be the high level of comfort and services that are offered onboard. We have not compared ships with regard to comfort level so this hypothesis is not explored.

The average CO_2 emissions value for ships in category B is 471.5 g of CO_2 per p–km. The average daily fuel consumption ranged from 180 to 240 t with an average of 201 t for normal operation at sea.

[6] ALB stands for available lower berth. The ALB occupancy rate is based on two passenger per cabin. The occupancy rate can be greater than 100% because some cabins can accommodate three or more passengers.

Not surprisingly, there are huge differences in the CO_2 emissions values for category C where they range from 247.3 to 1,314.5 g CO_2 per p–km. Three ships have CO_2 emissions below 400 g CO_2 per p–km; they were 15, 18, and 21 years old and carry between 445 and 1250 passengers with an ALB occupancy rate between 90.5 and 109%. Twelve ships in category C have a CO_2 emissions value between 400 and 750 g CO_2 per p–km.

Three ships in category C have an emissions value above 750 g CO_2 per p–km. This could be explained by low (less than 70%) ALB occupancy rates. An ALB occupancy rate of 100% would have reduced the CO_2 emissions by between 27.0 and 35.6%. The age of the ships could also be an explanation—two of the ships were 25 and 30 years old.

The average CO_2 emissions values for ships in category C is 569.6 g CO_2 per p–km. Fuel use ranged from 37 to 142.25 t per day, with an average fuel consumption of 70.6 t per day for normal operation at sea.

In category D, we find a large variation of CO_2 emissions values between the ships. Two ships have values below 300 g CO_2 per p–km. The ships are 50 and 19 years old. The older ship carries fewer than 100 passengers. A possible explanation for the low fuel consumption for the older ship is that the onboard comfort is relatively less than that of newer ships. The rest of the ships in this category have values from 722.8 to 838.2 g CO_2 per p–km. The average CO_2 emissions value for ships in category D is 554.1 g CO_2 per p–km. The average fuel use for this ship category is 11.7 t per day for normal operation at sea.

To summarise, our findings show that the average fuel consumption decreases when the ship's size also decreases. The only exception is the ship in category A that has a very low consumption. Some of the differences between individual ships that have a similar size could be the number of passengers, their ALB occupancy rate, and the ship's age. As outlined by Howitt et al. (2010), differences between individual ships could also be explained by the age of the engines, the level of comfort onboard, the number of crew, and the services the vessel offers. However, these factors were not explored in this case study.

Comparison with other modes of transport and forms of travel

In this section, we compare the energy use by cruise ships and their emissions at two levels. First we compare with other forms of passenger transport on the basis of emissions per passenger–kilometre. CO_2 emissions from cruise ships consist of two components: the propulsion and manoeuvring part and the ship as a hotel and a place of residence. These two components raise the question of how to compare cruise ships with other modes of transport.

Comparison with other modes of transport

Are flights, cars trips, and bus tours comparable to cruises? To make them comparable, we removed the time spent in harbour and the residence part of the cruise ships from the calculation; this is approximately 30% of the energy use (Howitt et al. 2010, RCCL 2008). We used the Statistics Norway (2008) conversion factor where HFO is assumed to have an energy content of 40.6 MJ/kg to find the energy consumption. We used a gross direct energy addition and a CO_2 emissions factor of 1.13 (for further information on how this was derived, see the section on gross direct energy use under methodology).

Table 4 *Energy consumption per passenger–kilometre for different modes of transport*

Estimate	Direct energy use in MJ per passenger–kilometre	Gross direct energy chain-addition	Sum
Passenger car (diesel)	0.829	0.133	0.962
Passenger car(gasoline)	0.940	0.132	1.072
Express bus	0.710	0.106	0.816
Regional train	0.598	0.137	0.735
Boeing 737 (400 km)	2.599	0.392	2.991
Boeing 737 (950 km)	2.160	0.326	2.486
Dash 8–100	3.384	0.916	4.300
Cruise ship (Norwegian case study)	1.80–11.94	0.252–1.552	2.192–13.492
Weighted mean Norwegian cruises	3.698	0. 481	4.179

Table 5 *CO_2 emissions per passenger–kilometre for different modes of transport*

Estimate	Direct CO_2 emissions per passenger–kilometre	Gross direct energy chain- addition	Sum
Passenger car (diesel)	61.6	11.8	73.4
Passenger car(gasoline)	69.4	11.7	81.1
Express bus	52.2	8.2	60.4
Regional train	0.0	1.1	1.1
Boeing 737 (400 km)	191	30.7	221.7
Boeing 737 (950 km)	158	25.5	183.5
Dash 8–100	248	39.9	287.9
Cruise ship (Norwegian case study)	139–920.15	38.1–233.5	157.1–1039.8
Weighted mean Norwegian cruises	285	37.1	322.1

The results show that only the emissions for cruise ships at the lower end of the scale are comparable to the Dash 8-100. The weighted mean is higher both for energy consumption and CO_2 emissions compared to all other modes of transport even if we only calculated the energy required for propulsions of the ships.

Comparison with other forms of tourism travels

In this section, we compare cruise travel with other forms of travel. It is challenging to make such a comparison since it is difficult to find the alternative of a cruise. Is it reasonable to believe that the alternative for a cruise to Norway would be a plane flight, a car ride, or a bus tour? Or would a traveller choose another location altogether, such as a cruise to New Zealand or a long intercontinental flight? How should we compare different forms of travels — per passenger, per passenger–day, or per journey?

We have chosen to compare travel to Norway by bus, car, and airplane per passenger–day. To make them comparable, we assume that the travel by plane, bus, and car is done from the northern part of Germany to the western and southern part of Norway since cruises are likely to start in Hamburg or Kiel. For the bus and car travel, information about the route is derived from a travel agency (see Appendix 2). For the flight travel, we have estimated travel by plane between Bergen and Hamburg and travel by plane between Trondheim and Hamburg. We allocate the round trip to take 7 days, which equals the average length of cruises to Norway. For the bus, car, and plane travels, we assume that the overnight stays are in hotels. The energy consumption for an overnight hotel stay is derived from Hille et al. (2011 p. 63), and we assume 172.8 MJ per guest–night. For the bus tour, we have applied a 90% occupancy rate (this is different from the values described in Table 2 and 3) since tour buses are likely to have a higher occupancy rate than normal Norwegian buses used for passenger transport on specific routes. For the car, we assume an occupancy rate of two persons per car. For the bus and car travel, we have included overnight stays at hotels and also ferry tours from the continent to Norway. For a further outline of our assumptions concerning this calculation, see Appendix 2.

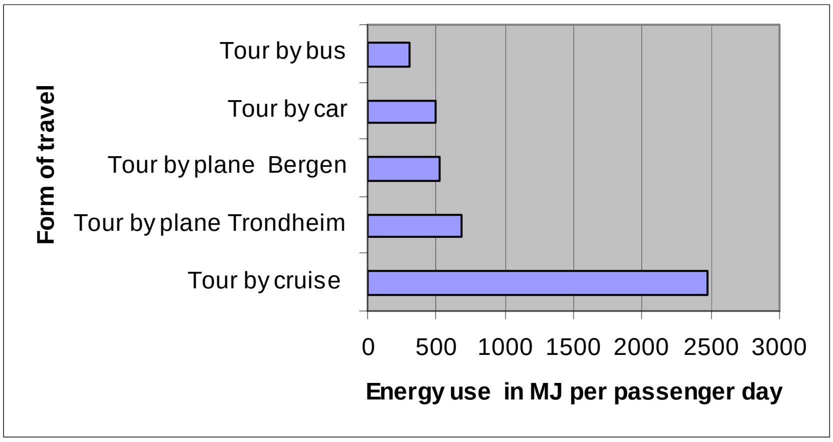

Figure 1 *Energy use per passenger–day for different forms of tourist travels from Germany to Norway*

The result shows that the direct energy consumption by cruise ships in our study is 3.6 times higher than for travel by plane and a hotel overnight stay in Trondheim, and 4.9 higher for a flight and hotel stay in Bergen because of shorter flight distances. For the bus and car, the differences were a factor of 5 and 8.2, respectively. This clearly shows that cruises are an unfavourable mode of travel from the northern part of Germany to the western and southern part of Norway when compared to other modes of travel.

However, the result must be interpreted with care since the assumed travel distances by different modes of travel vary. The flight tour score is surprisingly low since we only assumed travel to and from Bergen and Trondheim, and because the travel was divided over 7 days. This gives an average daily travel distance of 209.7 and 313.1 km. For the bus and car travel, we have assumed an average travel distance of 396 km. This is considerably less than for the cruise (468 km). If we had compared the different modes of travel with regard to greenhouse gas emissions this would have given the flight tour a less favourable score than that of the other modes of travel since aviation has an impact on radiative forcing. A main question that needs further analysis is whether these different modes of travel are real substitutes for each other.

Calculations of CO_2 emissions from cruises to Norway

Statistics (Rideng and Haukeland 2009, personal communication) show that Norway has experienced a steep increase in the number of cruise ship passengers since the 1980s. In 2009, for example, 430,000 passengers visited Norway as compared to 58,892 in 1985.

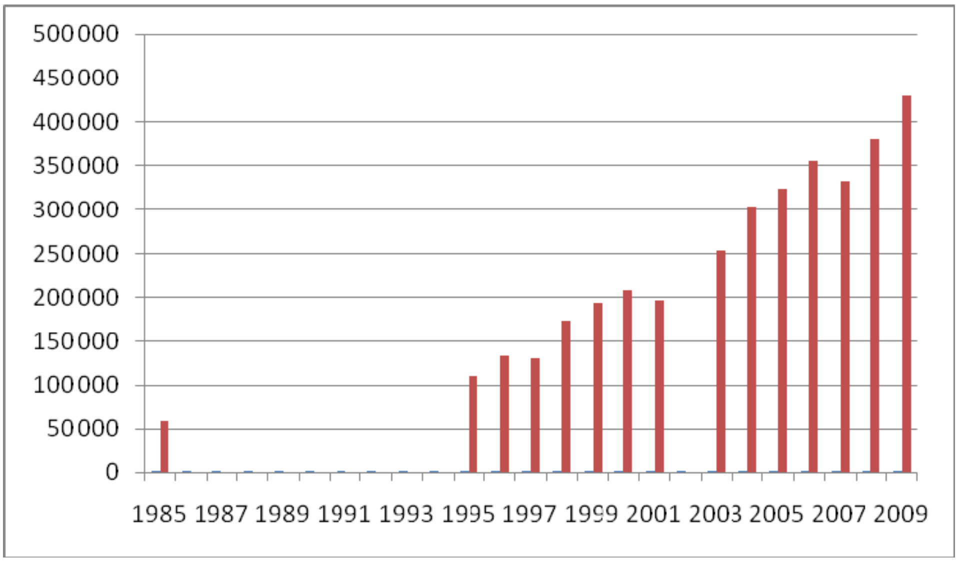

Figure 2 *Yearly number of cruise passengers to Norway 1985–2009*

In this part of our analysis, we have chosen to calculate the total emissions that were generated by cruise passengers to Norway in the year 2005. In 2005, 324,000 cruise ship passengers visited Norway. Of these passengers, we estimate that 127,659 are one-day passengers and 196,341 are passengers with more than a one-day cruise. In 2005, there were 1,296,000 “day visits” that were connected to cruise traffic (Rideng and Haukeland 2005). By subtracting the number of one-day passengers, we end up with 1,168,341 day visits. We divide the number of one-day visits by the number of passengers that have more than a one-day stay in Norway (196,341), which gives an average length of time of 5.95 days (approximately 6 days). However, this time does not include the time spent sailing both to and from Norwegian harbours. Most passengers sailing to Norway leave from Southampton, England; Le Havre, France; Rotterdam in the Netherlands; Hamburg, Germany; or Copenhagen, Denmark. The distances from Copenhagen / Hamburg / Rotterdam to Bergen are from 430–513 NM, i.e., it would take 21–26 hours at 20 knots to sail to Bergen. From Southampton or Le Havre, it would take about 30 hours sailing at 20 knots. We do not know how the passengers were distributed among these harbours, but we added 2 days for the time spent sailing to and from international harbours as a first approximation. We reduced this to 1 extra day because the “half day” was accounted for in the harbours’ statistics as a “day visit”.

We did not calculate the travel distances for all ships that operate in Norway. The average number of passengers and the size of the ships sailing to Norway appear to be smaller than the world average. Bergen and Oslo port authorities reported an average of 1,088 passengers in 2010, which is considerably less than the world average, as shown by Carnival's average carrying capacity of 1,950 passengers. However, the weighted mean in our case study implies that the size of cruise ships is larger than the average. We use a weighted mean of 190.6 kg CO_2 per p–day as a point of departure for our calculation. However, this value must be interpreted with care since the actual CO_2 emissions could be considerably different. As the previous outline shows, our weighted mean is not fully representative of cruise ships that arrive in Bergen. We have made an underestimation for the largest ship in our sample, and have not taken into account ships that sail to Oslo; this could imply that the emissions per passenger–day are less. Our average sailing distances and assumption connected to sailing and time spent in harbour are based on a small number of cases. Our average of 468 km is considerable less than average sailing distance of 545 km as estimated by information from Carnival Cooperation cruises (2009a, 2009b). We do the calculation for the year 2005 on the basis of 2010 data which could be faulty since ships could be older and less environmentally friendly in 2005.

Table 6 *Number of passengers and CO_2 emissions from cruise ships sailing to Norway in 2005*

Type of activity	Number of passengers	CO_2 emissions in tonnes
Tourists — one-day trip to Oslo	127,659	24,331.8
Cruise trips between harbours in Norway	196,341	261,958.2
Sailing to and from Norway	196,341	37,422,6
Total	**324,000**	**323,712.6**

We multiplied these numbers by a factor of 1.13 to obtain gross direct emissions, because we assume that only HFO was used. The gross direct CO_2 emissions were approximately 365,795 t of CO_2 in 2005.

Strategies for curbing energy use and CO_2 emissions

IMO is currently responsible for reducing emissions from shipping, but Haites (2009) points out that efforts to reduce emissions from international shipping have been unsuccessful. Binding emissions reduction targets or measures have not been adopted by global policy makers, IMO, or the shipping industry.

One strategy for reducing energy use is based on the idea that it is possible to ameliorate the environmental problems caused by transport by developing new and more efficient technologies to replace the old, inefficient, and polluting materials and methods. Examples of this approach could be the development of more efficient engines, lighter materials, and catalytic devices for cleaning exhaust, and the use of alternative fuels (Høyer and Holden 2007). Improvements of this type could be done throughout the life cycle of cruise ships, reducing the energy required for propulsion as well as reducing emissions. Developments in recent years, such as electrical motors, have made cruise ships more energy efficient (Atmosfair). In some cases, cruise ships have also been connected to the electrical grid, while in harbour, to reduce emissions.

The use of biofuels has also been mentioned as a strategy for reducing emissions from cruise ships. This will involve trade-offs between a reduction in direct CO_2 emissions and an increase in energy usage to produce the fuels. In addition, the cultivation of crops for fuel may lead to ethical questions on whether to use land and crops for food or for fuel production. In 2006 and 2007, RCCL was one of the world's single largest end users of biodiesel, which is a cleaner burning diesel fuel made from natural, renewable sources, such as vegetable oils. According to RCCL (2009), biodiesel use presented some operational challenges. RCCL stopped its initiative because an increased demand for biofuels was causing an increase in global prices for food like corn and sugar, and also causing deforestation. A third reason was the changing economics of biodiesel use, which stopped its consumption. Also, while the consumption of biofuels could be CO_2 neutral in the operating phase, emissions associated with land use and energy consumption during production of biofuels are another matter.

Reduction of the embodied energy and greenhouse gas emissions for the construction, maintenance, and operation of related infrastructure, such as the harbours and shipyards is another possible strategy. A lack of transparency from cruise ship companies and shipyards prevents the calculation of emissions in a life cycle perspective. A life cycle perspective is important for highlighting trade-offs in the cruise ship life cycle. There could be lower direct emissions per passenger–kilometre from newer and larger cruise ships, but these ships will most likely involve increased indirect emissions related to building the ships and harbour improvements.

A possible reduction strategy is to promote cruise pattern that are more environmentally benign and energy efficient, such as shorter and slower cruises, and/or to change modes of travel to and from departure points. However, our analysis shows that cruise ships already operate at slow speeds, so there is probably not the same potential for this to reduce emissions as it would be for freighters. A change to slower and shorter cruises could also cause an increase in local and regional pollution since more time is likely to be spent on shore or near land.

However, the rapidly increasing number of passengers on cruises could impede the efficiency and the substitution route, i.e. actions to reduce the amount of CO_2 will be impeded by the increased number of cruise passengers.

Conclusion

Different sources (including Carnival Corporation and RCCL) confirm that cruise ships have high energy consumption and CO_2 emissions on a per tourist basis. There seems to be a large individual diversity connected to energy use and the emissions factor for specific cruise ships. In our case study, emissions ranged from 198.8 to 1,314.5 g CO_2 per p–km.

There has been a sharp increase in the number of cruise ship passengers with an annual growth rate of 7.4% worldwide since 1990. This growth is also seen in cruises to Norway, which saw 130,000 cruise ship passengers in 1995 to 430,000 in 2009. In 2005, 324,000 cruise ship passengers visited Norway. Our calculations suggest that the gross direct CO_2 emissions associated with cruises in Norway for that year were approximately 365,795 t.

More transparency concerning the emissions figures from the cruise industry is needed in the search for effective strategies for reducing emissions. Carnival Corporation and RCCL provide aggregate figures for their entire fleet instead of figures for individual ships or journeys. Newer and larger cruise ships tend to be more energy efficient, but there may be a trade-off, with the construction phase being more energy intensive than it was for older ships. Shipyards have withheld information about energy use and emissions connected to the production of cruise ships; therefore, this hypothesis has not been explored.

References

Atmosfair (2010) https://www.atmosfair.de/kompensieren/jetzt-kompensieren/kreuzfahrt/. Last accessed on 08.03.2011.

Buhaug, Ø; Corbett, J. J.; Endresen, Ø; Eyring, V.; Faber, J.; Hanayama, S.; Lee, D. S.; Lee, D.; Lindstad, H.; Mjelde, A. (2008). *Updated Study on Greenhouse Gas Emissions from Ships: Phase I Report.* International Maritime Organization (IMO) London, UK.

Buhaug, Ø; Corbett, J. J.; Endresen, Ø; Eyring, V.; Faber, J.; Hanayama, S.; Lee, D. S.; Lee, D.; Lindstad, H.; Markowska, A. Z. (2009). *Second IMO GHG Study 2009*. International Maritime Organization (IMO) London, UK.

Carnival. Corporation (2009a). *Environmental management report: Fiscal year 2008*. Miami: Carnival Corporation& plc.

Carnival Corporation (2009b). *Carnival Annual Report 2008.* Miami: Carnival Corporation & plc.

Cicero (2011) http://www.cicero.uio.no/fulltext/index.aspx?id=5903&lang=no Last accessed on 08.03.2011.

CLIA (2009). CLIA cruise market overview: statistical cruise industry data through 2008. Cruise Lines International Association.

Cruise Norway: http://www.cruise-norway.no/CDA/homepg.aspx Last accessed on 08.03.2011

DEFRA (2008) *Guidelines to DEFRAS GHG Conversion Factors: Methodology Paper for Transport Emission Factors*. http://www.defra.gov.uk/environment/business/reporting/pdf/passenger–transport.pdf Last accessed on 09.03.2011.

Eijgelaar, E.; Thaper, C.; Peeters, P. M. (2010). *Antarctic cruise tourism: the paradoxes of ambassadorship, "last chance tourism" and GHG emissions.* Journal of Sustainable Tourism, 18(3),PP. 337-354

Gössling, S (2011) *Carbon Management in Tourism Mitigating the impacts on climate change.* Routledge International Series in Tourism, Business and Management. Routledge, Milton Park, Abingdon, Oxon, OX14 4RN, UK.

Haites, E. (2009). Linking emissions trading schemes for international aviation and shipping emissions. *Climate Policy* 9: 415–430.

Hille, J. Vik, M.L., Peters, P. (2011) Background for scenario making. Sustainable Destination Norway 2025. Vestlandsforsking note 1/2011.

Howitt, O. Revol, V. Smith, I. J. Rodger, C. J. (2010) C*arbon emissions from international cruise ship passengers travel to and from New Zealand* Energy Policy 38 PP. 2552-2560

Høyer, K.G.; Heiberg, E (1993). *Persontransport-Konsekvenser for Energi og Miljø, 1/93*; Western Norway Research Institute: Sogndal, Norway,.

Høyer, K.G.; Holden, E (2007). *Alternative fuels and sustainable mobility: Is the future road paved by biofuels, electricity or hydrogen?* Int. J. Altern. Propulsion 4 PP. 352–368.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 2: Energy, Prepared by the National Greenhouse Gas Inventories Programme*. Japan: Institute for Global Environmental Strategies.

Mintel (2008). *Cruises International.* London: Mintel Oxygen.

Maes, F., Coene, J., Goerlandt, F., De Meyer, P., Volckaert, A., Le Roy, D., De Wachter, B., Van Ypersele, J.P., Marbaix, P., 2007. Emissions of CO_2, SO_2 and NO_x from ships (ECOSONOS). Part 2: Global change, Ecosystems and Biodiversity. Final report. EV/44. Research in the framework of the Belgian Science Policy, Brussels. www.belspo.be/belspo/home/publ/pub_ostc/EV/rappEV44_en.pdf. Accessed 14 February 2010.

Rideng, A., Haukeland, J.V. (2006) *Gjesteundersøkelsen 2005*. Transport økonomisk institutt

Rideng, A., Haukeland, J.V (2010). G*jesteundersøkelsen 2009*. Transport økonomisk institutt.

Royal Caribbean Cruises LTD (2009) *2008 Annual Report*

Simonsen, M. (2010) *Transport, energi og miljø. - Sluttrapport* Vestlandsforsking-rapport nr. |/2010

Sea-Web (2010) http://www.sea-web.com/

Spielmann, M., Dones, R.; Bauer C. *Life Cycle Inventories of Transport Services*; Ecoinvent report No. 14. Swiss Centre for Life Cycle Inventories, Dübendorf. Switzerland.

Statistics Norway (2008): Energiforbruk og utslipp til luft fra innenlandsk transport Rapport 2008:49

The Carbon War Room (2011) www.carbonwarroom.com/battle/shipping Last accessed on 09.03.2011
VTT (technical research center of Finland)

Trozzi, C., & Vaccaro, R. (1998). *Methodologies for estimating air pollutant emissions from ships*. Rome: Techne.

Personal communication

Margrete Austad, Oslo havnevesen. 18.02.2010
Jon Erik Bastansen, NRK. 25.01.2011
Petter Dybedal, TØI. 15.02.2010
Maik Höhne, Atmosfair. 16.02.2010
Helen Hovland, Bergen havnevesen. 28.01.2010, 24.01.2011,

Appendix 1

As indicated in the section ”Additional travels for cruise tourism”, we calculated fuel consumption for both a Mediterranean cruise and a Caribbean cruise.

Consumption is calculated as a function of engine capacity. According to information from Atmosfair (pers. comm.), the specific cruise ship that we used for this calculation has the following engine and boiler capacity:

Main engine (ME): 42 MW
Auxiliary engine (AE): 34.6 MW
Boiler for additional heating (B): 5 MW

For calculating the CO_2 emissions for this ship we use the same methodology as Atmosfair. The engines run at different capacities under sail and in port. It is assumed that at sea, the main engine and the auxiliary engine run at 86 and 80 percent of full capacity, respectively. To calculate fuel consumption (tonnes) at sea, we multiply by a specific fuel consumption rate, which is assumed to be 180 g/kWh, as follows:

[A1] (0.86ME + 0.80AE) * 180 = 11484

For operating in the harbor it is assumed that the auxiliary engine operates at 64 percent of total capacity and the boiler is operating at full capacity. To calculate fuel consumption (tonnes) in port, we multiply by a special fuel consumption rate, which is assumed to be 180 g/kW≅h in this case as well:

[A2] (0.64AE + B) * 180 = 4885.92

For the Caribbean cruise, which starts and ends in Miami, we used information about the tour (per. comm.) to make the following assumptions:

- 34 hours are spent in port
- 124.5 hours are spent sailing
- The total of 158.5 hours is equivalent to 6.6 days
- 4000 passengers travel on one cruise
- Total distance covered is 3276.5 km (Netpas distance, 2.8)

The total fuel consumption for this cruise will be a function of total hours sailing and total hours spent in port:

[A3] (11285 * 124.5) + (4885.9 * 34) = 1598.5

Thus, this Caribbean cruise consumes 1598.5 t of fuel. If we use 3.13 as the CO_2 conversion factor (Buhaug et al. 2009; Howitt et al. 2010), we get a total of 5003 t of CO_2 emitted during this tour, or 1251 kg of CO_2 per passenger.

For this cruise we also have to take into consideration the additional travel by plane from Oslo to Miami and back, a distance of 15 234 km (http://gc.kls2.com/). We use a CO_2 emissions factor of 105.6 g per p–km for long intercontinental flights (DEFRA 2008), equivalent to 1608.7 kg of CO_2 per passenger. If we chose to take into account the global-warming potential of high-altitude emissions of gases other than CO_2 and we assume a decay period of 100 years, we must multiply the CO_2 due to fuel consumption by 1.8 (Cicero 2011), thus giving total CO_2 emissions of 2895.6 kg per passenger for this flight.

The total emissions for this Caribbean cruise, including the additional plane travel to and from Norway, are 4146.6 kg of CO_2 per passenger. The air travel accounts for 69.8% of the total CO_2 emissions from this journey.

For the Mediterranean cruise, which starts and ends in Barcelona, we used information about the tour (www.cruisecompete.com/itins/liberty_of_the_seas_cruises_jbedfgh.html) to make the following assumptions:

- 60 hours are spent in port
- 94 hours are spent sailing
- The total of 154 hours is equivalent to 6.4 days
- 4000 people travel on one cruise
- Total distance covered is 2442.8 km (Netpas distance, 2.8)

The total CO_2 emissions for this cruise amount to 1074 kg per passenger. The distance between Oslo and Barcelona and back again is 4312 km. Using a CO_2 emissions factor of 130.4 g per p–km for European flights (DEFRA 2008) and an additional factor of 1.8 for high-altitude emissions of other gases, we get a total of 1013.4 kg of CO_2 for the flight to and from Barcelona. The total CO_2 emissions for this journey, including flight to and from point of departure, are 2087.5 kg. The air travel accounts for 48.5% of the total CO_2 emissions.

Appendix 2

In this section we outline the assumptions we used to estimate energy consumption for different transport modes and forms of travel to Norway from Germany.

Table A7 *Direct energy use per passenger–kilometre and per hotel guest–night*

Category	Energy use (MJ per person–km or per guest–night)
Car diesel (2 persons)	0.829
Tour bus (90% occupancy)[a]	0.275
Hotel guest–night	172.8
Flight to and from Europe[b]	1.796
North Sea ferry[c]	1.793

Source: Sataøen and Andersen (2006), DEFRA (2008), SSB (2008), Simonsen (2010), Hille et al. (2011), Stenaline (2011).

[a] We converted data for an express bus (Simonsen 2010) to represent a 90% occupancy rate.

[b] We converted a CO_2 emission factor for European flight (DEFRA 2008) into energy by using information from SSB about fuel energy content (http://www.ssb.no/magasinet/miljo/tabell.html).

[c] We used information from Sataøen and Andersen (2006, p. 21) on fuel use for the North Sea ferry *Stena Saga* and converted this into energy on the basis of information from Statistics Norway (http://www.ssb.no/magasinet/miljo/tabell.html). We have assumed 2000 passengers, since this is given as the passenger capacity for *Stena Saga* on the Stena Lines web pages (http://www.stenaline.no/ferge/vare-skip/stena-saga/). The allocations between freight and passengers are based on the number of decks used for freight and passenger transport.

For car and bus travel, we used information about a bus tour from Germany called Des Westen Norweges erleben, which goes to the western and southern parts of Norwav (http://www.buswelt.de/).

Table A8 *Assumed travel distances and energy use for car and bus travel to Norway from Germany*

Travel to and from	Travel distance[a] (km per hotel night)	Energy use by car (MJ)	Energy use by bus (MJ)
Döbeln–Hirtshals	974	807.45	267.85
Hirtshals.–Kristiansand	133	231.41	231.41
Kristiansand–Hovden	271	224.66	74.53
Hovden–Bergen	338	280.20	92.95
Bergen–Måløy (vis.veg)	335	277.72	92.13
Måløy–Ålesund	144	119.38	39.60
Ålesund–Vinstra	300	248.70	82.50
Vinstra–Maihaugen	83.5	69.22	22.96
Maihaugen–Oslo	185	153.37	50.88
Oslo–Gothenborg	293	242.90	80.58
Gothenborg–Kiel	346	602.02	602.02
Kiel–Döbeln	555	460.10	152.63
Nights in hotel	7	1209.60	1209.60
Total energy in MJ per passenger	**3957.5**	**4926.71**	**2999.62**
Average per day per passenger	**395.75**	**492.67**	**299.96**

[a] We used google.map to find the travel distances.

For the tour including an air flight we gathered distances from Great Circle Mapper (http://gc.kls2.com/).

Table A9 *Energy use for flight from Hamburg to Bergen*

Category	Energy use (MJ per passenger)
Flight to Bergen and back	2859.2
5 days in hotel	864.0
Total energy use for journey	3723.2
Energy use per day	532.0

Table A10 *Energy use for flight from Hamburg to Trondheim*

Category	Energy use per. passenger in MJ
Flight to Trondheim and back	3936.8
5 days in hotel	864.0
Total energy use for journey	4800.2
Energy use per day	685.8