Environmental Advances 5 (2021) 100104

Contents lists available at ScienceDirect

Environmental Advances

journal homepage: www.sciencedirect.com/journal/environmental-advances

The who, why and where of Norway's CO_2 emissions from tourist travel

Henrik Grythe[a], Susana Lopez-Aparicio[*,1,a]

NILU - Norwegian Institute for Air Research, 2027-Kjeller,Norway

ARTICLE INFO

Keywords:
CO_2 Emissions
Tourism
Aviation
Cruise
Market emissions

ABSTRACT

We present CO_2 emissions from Norway's tourist travel by the available transport modes, i.e., aviation, maritime (ferries and cruises) and land-based transport (road and railways). Our study includes detailed information on both domestic and international tourist travel within, from and to Norway. We have coupled statistics from several large surveys with detailed emission data to allow us to separate the purpose of the travel (holiday or business).

Total transport CO_2 emissions for tourists in 2018 were estimated to be 8 530 kt, equivalent to 19% of the reported Norwegian national CO_2 emissions. Of these emissions, international tourists visiting Norway were responsible for 3 273 kt CO_2, whereas travel by Norwegians accounted for 4 875 kt CO_2, most of which occur outside Norway's reporting obligations. Aviation and maritime transport were found to be the largest emission sources, responsible for 71% and 21% of total CO_2 emissions, respectively. The reduction due to the COVID-19 pandemic was approximately 60% in 2020, and was sustained throughout the year.

Our study shows that officially reported emissions, as limited to the countries territory, are not suitable for accurate evaluation of transport CO_2 emissions related to tourism. A consumer or tourist-based calculation gives a marked redistribution of emission responsibility. Our results indicate that emissions from Norwegian residents travelling abroad are 1 602 kt higher than those from tourists coming to Norway. This is driven by frequent trips to popular tourist destinations such as Spain, Thailand, Turkey and Greece. Globally consumer based calculations would shift the responsibility of emissions by tourists to the large wealthy nations, with the most international tourists. The understanding of emission distributed by population group or market support in addition the developing of marketing strategies to attract low emission tourist markets and create awareness among the nations with higher shares of international tourist.

1. Introduction

Tourism is a source of enjoyment and relaxation for individuals and offers economic opportunities to societies. Before the COVID-19 pandemic prompted restrictions on international and even regional and local travel, the tourism industry was estimated to contribute over 10% of the global GDP and employment (WTTC, 2017). However, the tourism industry also impacts local and global environments as an important contributor to emissions of greenhouse gases (GHGs; Lenzen et al. (2018)). The World Tourism Organisation (UNWTO) estimated that tourism accounted for 22% of global transport CO_2 emissions and projected an increase of this share towards 2030 (UNWTO, 2019). Thus tourism will have a key role in achieving a significant reduction of total emission. In May 2020, the UNWTO estimated a pandemic-related 20–30% loss in international tourist arrivals (UNTWO, 2020). As it turned out, this prognosis was an underestimate: the number of European international flights dropped by more than 80% in 2020 (Eurocontrol, 2020), and has remained low into 2021 in parallel with the continued travel restrictions due to COVID-19.

Knowledge on emissions is essential to design strategies towards efficient emission reduction. United Nations Framework Convention on Climate Change (UNFCCC) adapted a framework for national emissions reporting based on fuel sales. National CO_2 emissions are split per sectors that represent different fuel combustion activities. However, tourism is not a specific category; rather, it is an undefined share within several activities. Moreover, international aviation and navigation, essential transport modes of tourism, are excluded from the national reporting obligations (Eggleston et al., 2006). This exemption was established in the Kyoto Protocol (UNFCCC et al., 2009), due to methodological incompleteness and inconsistencies, and, in particular, the

* Corresponding author.
E-mail addresses: heg@nilu.no (H. Grythe), sla@nilu.no (S. Lopez-Aparicio).
[1] I am corresponding author

https://doi.org/10.1016/j.envadv.2021.100104
Received 23 August 2021; Accepted 24 August 2021
Available online 1 September 2021

difficulty of allocating emissions of international movement.

Several countries, including Norway, have measures and governmental mechanisms in place to develop sustainable tourism. As a country's obligations are to report emissions within its boundaries, emission reduction generally focus on its territory, and can make them insufficient to target the tourism sector (Sun et al., 2020). Planning for and monitoring progress towards low-emission transport and a sustainable tourist industry require that all transport emissions be quantified in detail. The argument of incomplete and inconsistent methodology posed on aviation is valid from a fuel sales perspective, and official reporting obligations, but does not apply if emissions are assigned to passengers as the consumers. The method of allocation of emissions from international travel to passengers is not new and the objections to this method, which has always been its reliability, is fading out with the continual improvement of data sources (Larsson et al., 2018).

The International Air Transport Association (IATA) annually provides estimates how much CO_2 is emitted worldwide due to aviation, but very little is known in relation to other aspects of air travel, such as who flies, international vs. domestic flights, aircraft types, and distances flown between ground stops (Graver et al., 2020). Detailed information of this type would make it possible to characterise the contribution from different modes of transport within tourism, and to understand the contribution from residents' tourism (domestic and international) versus that from international tourist. The potential for mitigating the effects of tourism-related transport can be better understood by analysing the disaggregated emissions associated with transport according to purpose (holiday and business) and country or region of origin (markets). This knowledge is essential, for instance, to design targeted marketing strategies that balance the socio-economic benefit from the tourism industry against low emissions.

Many scholars have paid attention to tourism and the emissions associated with (Gössling et al., 2019; Gössling, 2013). There is a clear consensus that transportation accounts for the largest share of emissions from tourism (Lenzen et al., 2018; Perch-Nielsen et al., 2010). However, there is not yet an standard methodology that can be used to calculate emissions from tourism. Based on the studies published in the literature, the boundaries considered in the design of the studies vary considerably, and therefore the results. Some scholars focus exclusively on direct emissions, whereas others include also indirect (Surugiu et al., 2012; Cadarso et al., 2015), likewise, studies scopes cover from emissions within regional or country boarders (Perch-Nielsen et al., 2010; Liu et al., 2011; Russo et al., 2020; Cadarso et al., 2015) to trans-regional mobility or to specific destinations (Peeters and Schouten, 2006; Howitt et al., 2010), as well as the influence of the different transport modes (Kamb et al., 2020, Lin, 2010) or socio-economic factors (Yang et al., 2015; Yang and Zhou, 2020).

The decision regarding emission boundaries and employed methodology is determined by the purpose of the study. Perch-Nielsen et al. (2010) estimated that tourism transportation accounted for 87% of carbon emissions produced by the entire tourism in Switzerland, and air transport represent the largest emissions. The study, however, does not discriminate between domestic and international tourists, and the emission's boundaries are represented by activities or services provided by resident companies. Therefore, tourist activity managed by others than Swiss companies are not considered within the emission estimates. In a study carried out by Dubois and Ceron (2006) the focus was on short and long distance travel by French residents as, in France, most of the tourism occurs within the country itself. According to these authors, very long distance trips and air transport are the major contributors to emissions, and specially by a small group of frequent travellers.

Globally, tourism sector has set a 50% emission reduction target by 2035 (WTTC, 2010), however, plans are not in place on how this emissions reductions can be achieved (Gössling (2013). The developing of marketing strategies to attract or de-mark markets based on environmental goals has been recognised as an efficient strategy towards emission reductions in tourism (Gössling et al., 2015; Hall, 2014). Hereby, detailed knowledge on emissions per market need to be established.

There is a strong link between sustainable tourism and sustainable mobility (Høyer, 2000), and transport is the largest source of GHG emission from tourism (Lenzen et al., 2018; UNWTO, 2008). Thus, in this study, we limit our focus to direct CO_2 emission from transport based on a consumer or tourist-based approach. We present transport-related CO_2 emission from Norway's tourism in 2018 at high level of detail, such as contribution per transport mode, domestic and international, specific tourist markets and purpose of the trip. The detailed breakdown of emissions is done for 2018 and followed by a comparison with 2019 and the COVID-19 pandemic year 2020. Thus, we also assess how the different modes of transport are affected by the pandemic. We combine and compare two perspectives; one focuses on Norwegian travellers, providing information on the travel choices made by Norwegians, as consumers, and the subsequent CO_2 emissions, and the other focuses on incoming tourists to Norway, as the markets or the tourist's origin. An important objective of our study is to provide solid knowledge for policy makers and local tourist operators for the development of sustainable tourism market strategies. By doing this, we aim to bridge several gaps that hamper effective planning aimed at rebuilding tourism as a low-emission industry in Norway by focusing on low emission tourist markets. In addition, the methodologies developed and proxies implemented in this study can be transferable to other countries and regions, as most of the required data exist globally.

2. Methodology

The purpose and end-use of emission data dictate the most suitable accounting method (e.g. Gössling, 2013; Tang et al., 2017). Calculating emissions from the transport of tourists from the consumer's perspective requires detailed input data. Based on the gathered data shown in Fig. 1, we have opted to use somewhat different approaches for each transport mode based on input data availability. Where possible, we use bottom-up methods, approaches based on highly detailed activity data and specific emission factors per transport technology. On one hand, this approach allows for very specific calculations, on the other, the data collection process is costly in terms of time and resources. The bottom-up estimates are not always directly comparable with results obtained using methods based on fuel sales, for instance, or the Tourism Satellite Account (TSA) framework recommended by the OECD.

We define tourists trips in accordance with the Eurostat definition, i.e., trips with an overnight stay away from home, and have further subdivided these into international and domestic trips, and for holiday and business purposes. CO_2 emissions per passenger were calculated for each different transport mode, hereby aviation, waterborne navigation, road transport and railways. We focus exclusively on direct CO_2 emissions and include all the main transport modes used by tourists. We considered only CO_2, and do not consider other climate forcing that can be important, such as Short-lived Climate Forcers (SLCF) or contrails from aviation. Several other studies have covered the relationship between CO_2 emissions and other GHG emissions from relevant sources (e.g. Aamaas and Peters, 2017). We also do not calculate indirect emissions, which would add emissions from activities such as drilling, refining and transporting the fuel used to a petrol station (i.e., Well-to-Wheel) and those associated with the manufacturing of the vehicles. Whereas including indirect emissions gives a more holistic representation of the impact or footprint of a given activity, it also adds several layers of uncertainty.

2.1. Aviation

Tourists emissions from aviation are calculated from specific data on aircraft movement for flights to, from and within Norway. In addition, all information from connecting tickets for outgoing passengers was

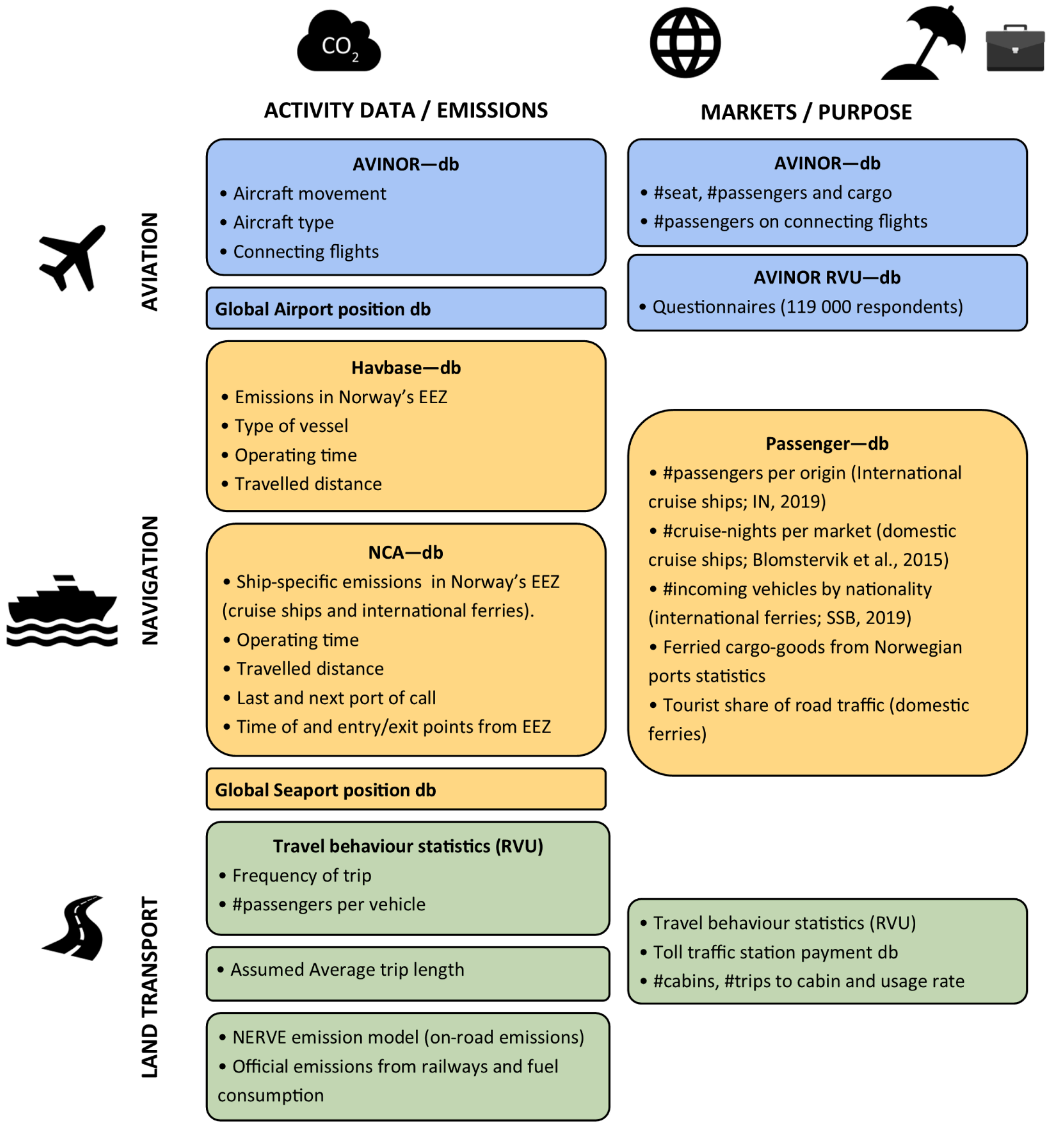

Fig. 1. Input data used in the calculation of emissions and distribution per market and purpose of the trip. #: number of. See text for more details.

used to determine the ultimate destination of each passenger. The dataset was provided by AVINOR AS, the state-owned company that operates nearly all Norwegian civil airports. The activity dataset (AVINOR - db in Fig. 1) includes information on the aircraft type, airline code and number of seats, passengers and cargo per flight for the years 2018 and 2019. The dataset also contains flights and their frequency for the few smaller airports not operated by AVINOR AS, giving a complete picture of all civil flight movements with at least one stop in Norway.

For each flight, the fuel consumption (kg) was calculated following the ICAO CORSIA model (ICAO, 2017). This model relies on ICAO aircraft type, specific emission factors per aircraft and the Great Circle Distance of each flight, calculated as the inter-airport distance based on a global set of position data of all airports with a 3-letter ICAO identification code (Global Airport position db in Fig. 1). In this way, 99.8% of all flights registered in the database with a stop in Norway were accounted for. The remaining 0.2% either had an unknown or an aircraft type with unknown emission factor. These flights mainly involved small aircraft and were ignored. For passengers with connecting tickets, we calculated passenger fuel consumption based on the connecting flight distance and the average emission factor (kgfuel / pkm) of flights of similar length. A flat conversion of 3.15 kg CO_2 / kgfuel was used to calculate CO_2 emissions and, as the dataset did not contain information on coach/business/1st class, the passenger kilometres (pkm) were calculated flat by the number of passengers. As connecting flight information is only available for outgoing passengers, we assumed that the same number of passengers were coming in from the same destinations. For cross-checking purposes, fuel consumption was also calculated based on the EUROCONTROL method (Eurocontrol, 2019) and showed a minimal difference with the ICAO CORSIA model. To calculate total emissions between Norway and each different destination, we assigned CO_2 emitted between Norway and the international hubs to the ultimate destination of the connecting flights.

An accompanying dataset ((AVINOR, 2019); AVINOR RVU-db in Fig. 1) was used to quantify the share of Norwegian and international passengers and their travel purpose. These data come from questionnaires handed out at airports in Norway, and included 119 000 respondents in 2018. The proportions of foreign to Norwegian travellers, and of business to holiday travel, were then calculated for each route and combined to national level. For net emissions, we subtracted the share of emissions attributed to incoming international passengers from that attributed to Norwegians travelling abroad for each specific country. The 2019–2020 emissions were calculated in the same way, except that the detailed passenger data was replaced by the coarser statistical data from AVINOR's website (AVINOR, 2021).

As flights frequently carry goods and post as well as passengers, aircraft fuel consumption and emissions were shared between passengers and goods (AVINOR - db; Fig. 1). To assign freight emissions, we used the IATA Recommended practice 1678 (IATA, 2014). The method recommends two equal approaches (A and B) and for our study we selected method B, where emissions are shared equally by weight as

$$TotalPassengerWeight(kg) = \#Seats \times 50kg + \#Passengers \times 100kg \quad (1)$$

where each seat is weighted as 50 kg and each passenger (including luggage) at 100 kg. The flight emissions are then distributed equally to each kg of the freighted goods and the total passenger weight.

2.2. Water-borne navigation

CO_2 emissions from the maritime transport of tourist were primarily based on monthly CO_2 emissions from passenger (ferries) and cruise vessels operating within the Norwegian Exclusive Economic Zone (EEZ; 200 nm from the coastline), for which data is publicly available through a web-portal (Havbase, 2021; Havbase - db in Fig. 1). The input data for emissions originate from the marine Automatic Identification System (AIS) and emissions are estimated by an in-house model at the Norwegian Coastal Administration. This in-house model has, to our knowledge, not been validated, but gives emissions estimates very similar to those produced by the STEAM model, which is used by IMO (Johansson et al., 2017).

A supplementary set of data on the travelled distance, operating time and emissions of individual vessels classified as cruise ships or international ferries was provided for 2018 by the Norwegian Coastal Administration for this study (NCA - db in Fig. 1). The dataset also contains information on when and where each vessel entered and exited Norwegian waters, along with last and next port of call given in the AIS at the time of entry or exit. The dataset also provides detailed information (e.g., name and IMO number) on both domestic and international cruise vessels, along with the international ferries operating between Norway, Sweden, Denmark and Germany. Emissions that occur outside Norway's EEZ were then calculated based on the Great Circle Distance between the point of entry and the port outside Norway using the same emission factor as while operating in Norwegian EEZ. To calculate passenger numbers, we produced a database with ship-specific information on the size (GT) and passenger capacity of ferries and cruise vessels. The passenger load factors for different types of ferries and cruises were then calculated based on the number of passengers that arrived by international ferries to various Norwegian ports (SSB, 2021b), the number of passengers travelling by domestic cruises per port of destination and arrival (SSB, 2021b) combined with the 2018 time schedule and the number of passengers that arrived to Norway by cruise ship per port (IN, 2019). Emissions in 2019 and 2020 were calculated in the same way.

The distribution of emissions to passengers was done per market (Fig. 1) based on the number of passengers per origin for international cruises (IN, 2019), the number of cruise nights per market for domestic cruises (Blomstervik et al., 2015) and the number of incoming vehicles by nationality and month in ferry services between Norway and foreign countries in 2002 from Statistics Norway (SSB, 2021b). Information on cargo goods on ferries was taken from Norwegian port's statistics.

To complement the overview of emissions from waterborne transport, and contribute to the understanding of emissions from Norwegians trips, emissions associated with Norwegians travelling abroad in cruise trips was estimated based on the number of passengers and the average number of days in a cruise trip (CLIA, 2018), using an average emission factor (138 kgCO_2/day), obtained as the average emission factor for large cruise ship in Norwegian waters.

As ferries carry cargo along with passengers, a share of emissions should be assigned to each type of service. However, there is no standard accepted method for apportioning emissions between passengers and cargo for ro-ro ferries. We therefore chose to use a volumetric approach suggested by Kristensen and Hagemeister (2012), where emissions are assigned to the transport of goods and passengers depending on the volume of the ship that they occupy. Following this approach, we used a volume of 24 m^3 per lane metre (67.5 m^3 per passenger car) and 7–13 m^3 per passenger depending on the ship comfort level. We calculated the share of emissions assuming for goods 2 000 kg per lane metre and a mean comfort level of 10 m^3 using annual report on passengers and goods for 2018 from the ports in Oslo, Kristiansand, Larvik and Sandefjord.

2.3. Land transport

Essentially all emissions from land-based transport should be accounted for in national fuel sales reporting. For road vehicles, our approach to calculate tourist emissions was to determine the share of road emissions that are due to holiday travel. Thus, the key parameter is the share of private car traffic that is associated with tourism. To determine this, the purpose of the journey must be known. In Norway, travel behaviour surveys have been carried out at regular intervals since 1985, and statistics on trips' frequency, length and purpose are reported every third year. Whilst the survey provides no data from which the overall activity from tourism can be extracted directly, it gives some key numbers. As the data made available in these travel behaviour reports vary, we have based our study on the two most recent reports (Epinion, 2019; Hjorthol et al., 2014) (Travel behaviour statistics (RVU) in Fig. 1). Some of the key metrics used in our study are:

- 18% of trips made by Norwegians are spare time leisure trips.
- Norwegians above the age of 13 go on 0.74 holiday trips per month.
- Long leisure trips (international trips and domestic trips $>$ 100 km) are made by car (24% and 74%), airplane (64% and 15%), train (1% and 7%), bus (2% and 4%) and ferry (7% and 1%).
- Cabins in Norway are used 30.4 nights per year over 12.4 trips.

For calculating the traffic volume and emissions due to tourism, an average trip length (km) and frequency of trip would be required, along with emission factors and the number of passengers per vehicle. We have applied and compared several methods based on available data, with similar results to the one presented here.

For vehicle emissions, we based most of our emissions on results from the Norwegian Emission from Vehicle Exhaust (NERVE) Model (Weydahl et al., 2018). This is a high-resolution emission model with details on all Norwegian-registered vehicles, roads and traffic capable of producing emissions down to single roads. From NERVE, and specific for 2018, we used the weighted average emission factor over all roads, vehicles and traffic situations for private cars (122.6 gkm^-1), and diesel buses (708 gkm^-1). These emission factors take into account road properties, congestion and vehicle age and EURO emission standard. For campers and mobile homes we used 285 gkm^-1. We assumed 20 passengers per bus, 1.86 per private car and 2.2 per camper (Hjorthol et al., 2014). We found no sources for average trip length and assumed a one direction driving distance of 170 km to cabins (the average distance of the main cabin hubs from Oslo and Bergen) and 250 km average for other holiday trips by car (assumed longer than the cabins on average). Estimates of general travel intensity were based on the portion of the population on holiday, and in the case of coaches and campers, we applied data on total annual driving distances.

Norway's emissions from rail are negligible compared to other transport modes as, with a few important exceptions, trains are electrified and therefore do not cause direct CO_2 emissions. Based on the detailed description available from Bane NOR, the Railway Infrastructure Company in Norway, railroads were evaluated to identify those operating on electricity and those on diesel. Only six of Norway's 30 train routes run on diesel (i.e., Nordlands- banen, Rørosbanen, Raumabanen, Solørbanen, Meråkerbanen and Stavne - Leangenbanen). Nevertheless, rail is a viable option for travelling long distances. CO_2 emissions were calculated from Norwegian official emissions reports for 2018. The share of fuel consumption by passenger trains relative to the total fuel consumption, including goods transport, reported by the Norwegian State Railways, was used to obtain the passenger train emissions. For instance, fuel consumption in 2018 by diesel passenger trains was 8.9 million litres, whereas the fuel consumption for railway freight transport was 6 million litres. Even though it is possible to estimate emissions from diesel trains, there is no known input data to identify what proportion of the passengers are tourists, so in this study we only report total emissions from trains and associated emission factors. However, we assessed the number of passengers who enter the country. According to (SSB, 2021b), very few people cross the Norwegian border by train (i.e., 441 752 passengers). Statistics and surveys are available down to individual rail-lines, showing numbers of seats, passengers and departures (SSB, 2021b), and indicating that 9% of holiday trips and 2% of business trips in Norway are done by train.

3. Results

3.1. Traveller's entrance into Norway

By our calculations, 29.4 million people entered Norway in 2018. Most of the passengers arriving by airplane, ferry, cruise ship and train would be staying overnight, meeting our definition of tourism, but for those arriving in private cars day-trips dominate. Fig. 2 shows all controlled points of entry into Norway for all transport modes, where the size of each circle is proportional to the number of passengers. The main entry is Gardermoen airport, where over 6.5 million passengers arrive by aircraft, followed by Svinesund and Magnor, road crossing points with Sweden, with 6 and 2.3 million passenger arrivals, respectively. In total, aircraft and road transport constitute the largest sources of visitors, with 13 and 10 million passengers, respectively. International ferries from Sweden, Germany or Denmark bring 2.9 million passengers. Cruise ships and trains contribute to a lesser degree to total passengers arriving to Norway, with 3 and 0.4 million passengers, respectively, in 2018 (Fig. 2).

The entry points show a wide geographical distribution. The total number of passengers that enter through the area around Oslo (inset area in Fig. 2) is around 20 million (67%). This area is the main entry point for all modes of transport barring cruise ships. Kristiansand in southern Norway has a large ferry entry point, but cruises spread along the entire coast, mainly the west coast and the Norwegian fjords. As the cruise information used in our study is based on AIS data, the passenger entry point does not necessarily always represent the first or last contact point of the cruise. For vehicles, there are several crossing points sparsely populated north, only a few main crossing points have significant traffic. In the far north, the archipelago of Svalbard is an important entry point, with approximately 78 000 passengers in 2018.

3.2. Aviation

Aviation is the largest source of CO_2 emissions from tourism transport (Table 1). CO_2 emissions (2018) from domestic and international tourist aviation were calculated to be 1 112 kt and 4 905 kt, respectively, and about 30% of the international aviation (i.e., 1 487 kt) is attributed to passengers on connecting flights, not touching Norway. CO_2 emissions reported to UNFCCC by Norway are similar for domestic aviation (i.e., 1 179 kt reported CO_2), whereas less than half is reported for international aviation (i.e., 1 720 kt reported CO_2). The differences between our estimates and the reported emissions rely on the methodology and input data behind emission estimates. Official reported data are

Table 1
CO_2 emissions (*kt*) related to tourism, subdivided by transport mode, and split between Norwegians (N) and tourists (I) and purpose of the trip, and cargo. NB: Norwegians travelling for business. NH: Norwegians travelling for holidays. IB: Tourists coming to Norway for business. IH: Tourists coming to Norway for holidays. Net (*kt*): CO_2 emissions from Norwegian travel - CO_2 emissions from tourist trips to Norway. n.a.: not applicable. Dom.: domestic Int.: international. -: lack of input data and therefore, not estimated.

Sub-sector	CO_2	NH	NB	IH	IB	Cargo	Net
Dom. Aviation	1 112	527	382	116	84	4	709
Int. Aviation	4 905	2286	378	1435	585	165	544
Cruise Ships	665	196	0	532	0	0	-336
Int. Ferries	1 062	505	0	408	0	149	97
Dom. Ferries	115	80	16	19	0*	n.a.	77*
Private Cars	671	501	76	94	0*	n.a.	483*
Total	8 530	4 023	852	2 604	669	318	1 602
Camper-van	-	83	0	-	0	n.a.	-
Buses	-	35	-	-	-	n.a.	-
Trains	26	-	-	-	-	n.a.	-

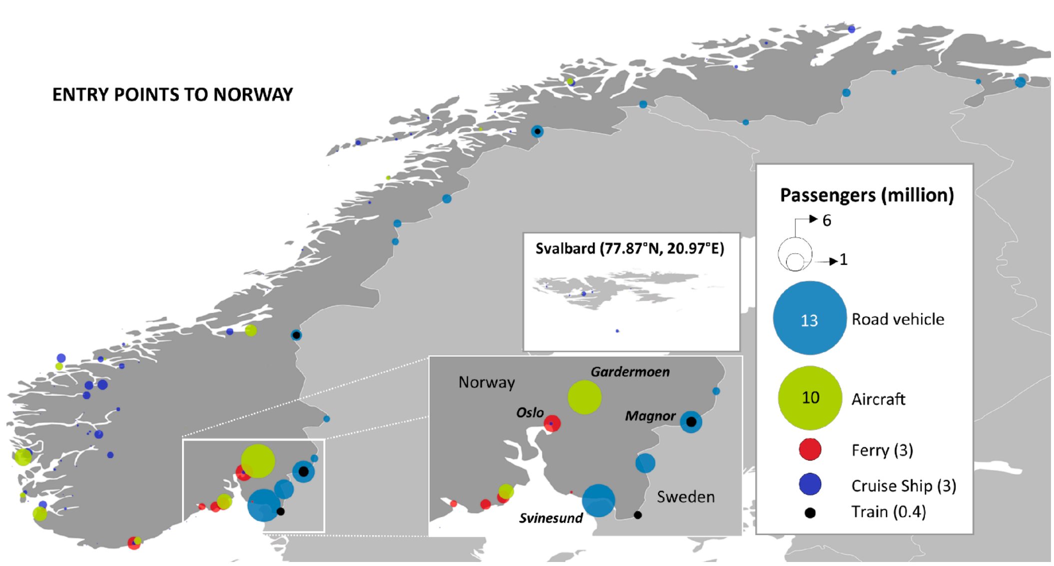

Fig. 2. Entry and exit points for passengers travelling to/from Norway. Geographical points denote the place and the size represents the volume of passengers, whereas the colour denotes the transport mode. Volume of passengers is the mean of entries and exits. Cruise ship arrival points are placed based on ship AIS data, where stated origin and destination reported by ship signal are used for vessels that cruise between Norway and another country.

derived from jet fuel sales for domestic and international routes. The slightly lower value we estimate for domestic aviation emissions compared with reported CO_2 may be associated with non-commercial flight in Norway (e.g., helicopters, cargo aircraft), which are included as part of the civil domestic aviation, and therefore in the official reporting of emissions, but not in our dataset. Our estimated CO_2 emissions from international aviation are over twice those officially reported. This is unsurprising given that, on average, half the fuel for a round trip would be purchased outside Norway, and the subsequent emissions would therefore be reported to UNFCCC by the country where the fuel was sold.

CO_2 emissions from aviation were linked to passengers and cargo, and calculated for all flight routes to, from and within Norway as indicated in Fig. 3. Here, the end destination airport includes connecting tickets and flights are shown as thin black lines. Each airport is represented by a grey circle, which size represents the number of end point passengers. Red and blue lines between Norway and the main markets are selected based on the total emission of all the routes between Norway and the market. Total emissions for each of the markets are represented by the pie diagrams, which size represents the total CO_2 emission. The pies show, in addition, the relative emission shares associated with Norwegian (NO) and international tourist (IN), travelling for holidays or business, and the calculated emissions from cargo entering to and departing from Norway. The emissions attributed to Norwegian passengers (a total of 3 573 kt CO_2 for domestic and international flights; Table 1) are 23% higher than the total CO_2 emissions reported to the UNFCCC (i.e., 2 899 kt CO_2). Thus, Norwegians are responsible for significantly more emissions as consumers (passengers) than as producers (fuel sale). A large contributing factor to this is our passenger emissions represent the entire air trip, which includes connecting flights which gives significantly higher total emissions than reported.

The total CO_2 emissions between Norway and each market are determined by the number of flights and the distance, and to a lesser degree also by the types of aircraft and cargo carried on the individual routes. Around 82% of the domestic CO_2 emissions are from Norwegians travelling for holidays (58%) or business (42%). Norwegian leisure travel is the single largest source of aviation emissions with 2 813 kt CO_2, including domestic and international trips. Markedly, international Norwegian holiday trips dominate emissions for the routes to Spain (78%), Greece (93%), Turkey (78%) and Thailand (61%), but there are also several other smaller markets where Norwegian tourist travel represents an important share of total emissions.

International aviation tourism to Norway, both on holidays and business trips, emit around 2 020 kt CO_2 (Table 1). The largest source of emissions within the international market is from the US-Norway (708 kt CO_2) and the UK-Norway routes (288 kt CO_2), but markets in Asia, Australia and New Zealand have a large share of international tourism (Fig. 3). These markets would almost certainly be missing from the emission overview without information on connecting flights, as their passengers predominantly arrive via European hubs, leaving just short flights in and out of Norway. For instance, the high emissions from the US-Norway route are also driven by long connecting flights within the USA. The data does not specify the citizenship of incoming international passengers; thus, for instance, international emissions from Spain cannot directly be coupled to Spanish passengers. However, as flight

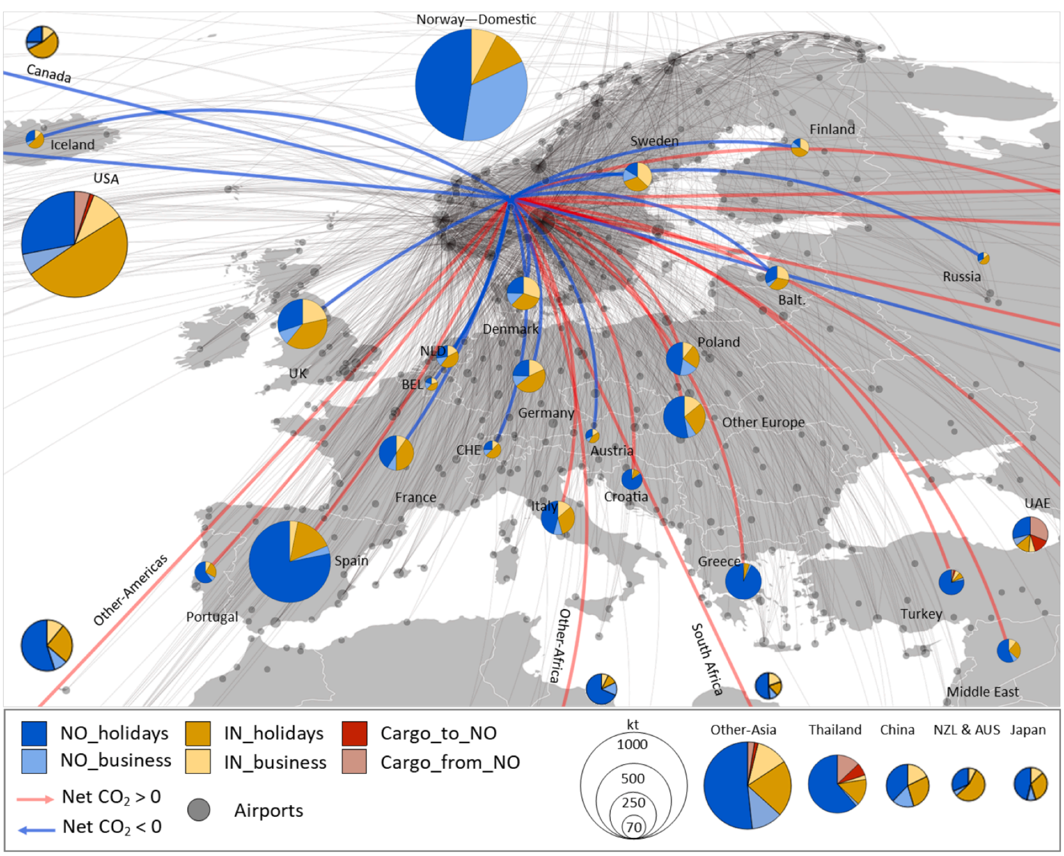

Fig. 3. CO_2 emissions from aviation between Norway and other countries. Pies: The size of each pie corresponds to total transport emissions between Norway and corresponding country. The pies' coloured sections represent the share of emissions from international tourists (yellow, IN) and Norwegian residents (blue, NO) that travel on holiday and business, and the cargo to/from Norway. The red and blue lines represent the net emissions; blue indicates dominance of international tourists coming to Norway (Net < 0) and red indicates dominance of Norwegians travelling abroad (Net > 0). Individual flight routes are shown in the background (black lines) as well as airports (grey circles, size proportional to the number of passengers) served by either direct or connecting flights. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

connections are in the dataset there is probably a strong relationship between emissions from Spain and emissions by Spanish passengers.

For each market, the net emissions are estimated as the difference between emissions from Norwegian residents travelling abroad and emissions from tourists coming to Norway. Thus, positive emissions represent higher emissions from outbound Norwegians than from incoming tourists from the same market, whereas the opposite yields negative emissions (Fig. 3). The largest net CO_2 emissions are driven by Norwegian holiday trips to Spain, Greece, Thailand and Turkey (Fig. 3). The largest negative net CO_2 emissions are driven by trips to the US, UK and Sweden. Holiday or leisure trips dominate total emissions with 4 363 kt CO_2 or 72% of total aviation emissions. Regarding aviation within Norway, emissions associated with holidays constitute 58% of total. For comparison, the holiday share reaches 77% of emissions in international aviation.

3.3. Water-borne navigation

Norway reported CO_2 emissions of 2 588 kt CO_2 for domestic navigation and an additional 676 kt CO_2 from international navigation (UNFCCC, 2021) for 2018. These numbers need to be carefully considered, as a correction of the figures for marine gas oil sales, and basis for the emission estimates, was announced in 2021. The correction indicated an under-reporting of emissions to UNFCCC between 2012 and 2019, with around 1.8 millions tons of CO_2 potentially under-reported in 2019 (SSB, 2021a). Our study therefore calculates emissions in 2018 based on AIS data for ships operating within the Norwegian EEZ (200 nm EEZ), which are at a total of 8 430 kt CO_2 (Havbase, 2021); 1 418 kt CO_2 from passenger vessels and 557 kt CO_2 from cruise ships. Passenger vessels (ferries) and cruise ships are the two means of water transportation of relevance for tourism. Ferries include domestic routes and international connections linking Norway with Sweden, Germany and Denmark. Similarly, cruise ships operate in both international and domestic traffic. Norwegian cruise ship routes operate year-round and serve not only as an important tourist activity in northern Norway, in the Norwegian fjords and in the Arctic, but also transport people and supplies along the coast.

Cruises

Norway is an important destination within the cruise industry, including trips to the Norwegian fjords and the Arctic. In 2018, 3.2 million tourists went on cruises in Norway (IN, 2019). This number contrasts with the 41 000 Norwegians travelling on international cruises to the Caribbean, Bahamas, Bermudas or the Mediterranean based on reporting from the Cruise Lines International Association (CLIA, 2018).

The results from our study indicate that domestic and international cruise ships visiting Norway emit 665 kt CO_2, about 20% higher than the AIS- based cruise emissions within the Norwegian EEZ. This additional 20% corresponds to the CO_2 emissions outside Norway's EEZ, as our study considered the complete trip. Cruise ships in and visiting Norway are alone responsible for emissions equivalent to all maritime international emissions reported by Norway to the UNFCCC (i.e., 676 kt CO_2; (UNFCCC, 2021)). Additionally, Norwegians travelling abroad in cruise trips to the Caribbean and Mediterranean seas are responsible for around 46 kt CO_2 (Fig. 4). The vast majority of cruise ship emissions (i.e., 532 kt CO_2) can be attributed to international passengers (Table 1). Only 30% of the passenger nights on domestic cruises involve Norwegians (Blomstervik et al., 2015), and there are few (if any) Norwegian passengers on board international cruises in Norway. Norwegian passengers on domestic cruise ships are responsible for the remaining emissions, with a total of 196 kt CO_2, as cargo is thought to be negligible on cruise ships.

From a market distribution perspective, the highest CO_2 emissions from tourists on cruise ships were estimated to be from Germany, UK and USA (Fig. 4). Several cruise lines operating out of Germany and UK sail to Norway. However, there are no regular trans-Atlantic cruise routes; thus, prospective passengers would have to fly to a port city in either Norway or elsewhere to go on a cruise in Norway. This will involve additional trip emissions, which are not accounted for. This is also the case for Norwegians on cruises elsewhere, but such emissions are included in the aviation accounting.

With regard to the purpose of the passengers going on a cruise, international cruises are exclusively assigned to holiday trips. Within the domestic cruises, there is a business segment (e.g., conferences, business meetings); however, data on purpose shares within domestic cruises was not available for this study.

International and Domestic Ferries

Our results show that 1 418 kt of CO_2 is emitted from passenger ships within the Norwegian EEZ, of which 876 kt CO_2 is from domestic ferries and 542 kt CO_2 is from international ferries. The latter also operate in international or other countries' waters, and these emissions also need to be considered. Based on our estimates, international ferries emit 519 kt CO_2 outside the Norwegian EEZ, giving a total of 1 062 kt CO_2

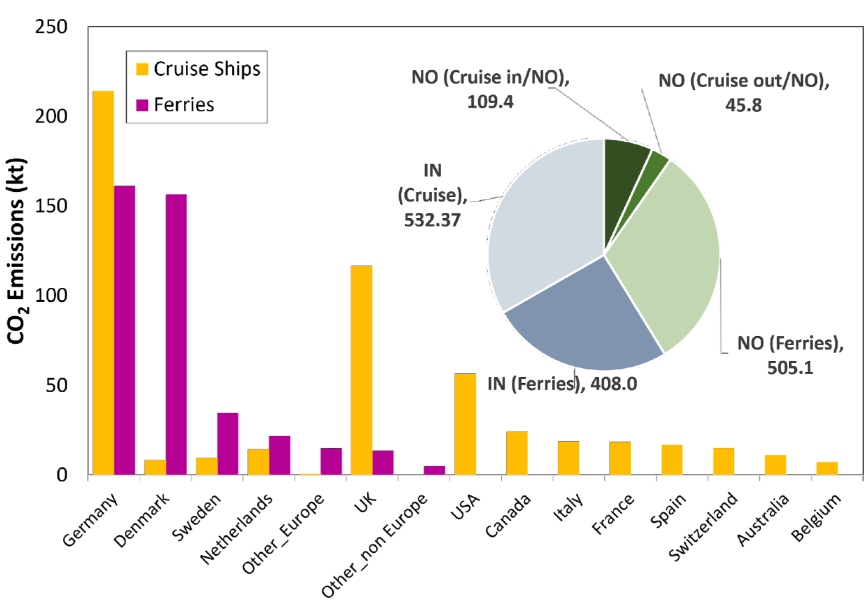

Fig. 4. Maritime CO_2 emissions from international ferries and cruise ships coming from and going to Norway. Bar graph: emissions from international ferries and cruise ships per tourist markets visiting Norway. Pie chart: Distribution of total CO_2 emissions from maritime transportation of international tourists coming to Norway (IN) by i) cruise ship and ii) ferry, and Norwegians travelling by i) international ferries (NO Ferries); ii) domestic cruise ships (NO Cruise in \NO); and iii) cruise ships outside Norwegian waters (NO_Cruise out\NO).

(Table 1). The largest share of emissions from international ferries is attributed to tourists from Germany (161 kt CO_2) and Denmark (157 kt CO_2), and to a lesser extent from The Netherlands (22 kt CO_2) and Sweden (35 kt CO_2) (Fig. 4). Comparing emissions from international tourists (408 kt CO_2) and Norwegians travelling abroad by ferries (505 kt CO_2), we obtain net positive emissions. This indicates a larger contribution from Norwegian travel behaviour to total emissions from transport-related tourism by international ferries.

Total emissions from domestic ferries were estimated to be 876 kt CO_2. However, only part of these emissions is associated with tourism. With few exceptions, large domestic ferries in Norway service road connections and are thus part of the Norwegian road transport system. Therefore, to estimate the tourists' share of emissions from domestic ferries, we use the same share obtained for road traffic of 15.6% (see Section 3.4). This results in 115 kt CO_2 emissions from tourism in domestic ferries (Table 1).

International ferries carry goods, cars and passengers. By volumetric distribution of emissions between goods and passengers, 14% of international ferry emissions are assigned to the transport of goods (Table 1). For the short ferry routes, goods transport is large, but on the overnight ferries passenger emissions dominate.

3.4. Land transport

The land emissions are dominated by emissions from road vehicles. The movement of tourists by land carries significantly higher uncertainties than for other transport modes as less is known about the purpose of each trip. Although overall traffic volumes and total driving distances are well known, assumptions have to be made on the trip's length and purpose (e.g., holiday, business, work-home commuting).

Norwegian private cars were driven a total of 35 000 million km and emitted 4 300 kt of CO_2 in 2018 (Weydahl et al., 2018). There are 13 676 buses registered in Norway, and CO_2 emissions from all buses are calculated to be 360 kt (Weydahl et al., 2018). In addition, Norway had an estimated 49 600 camper vans and 119 000 caravans in 2018 (Brekke et al., 2018). Camper vans had an average driving distance of 5 785 km per year (0.6% of total traffic) and an emission factor of about 285 $gCO_2\ km^{-}1$ (Brekke et al., 2018), which result in emissions of 83 kt CO_2 (Table 1). Movement by caravans is not registered in the same way as for other road vehicles, and even though they have no engine, they affect the emission factor of the vehicle pulling them. With the probable exception of camper vans, the part of road transport that is connected to tourism must be inferred from ancillary data. Despite the existence of vehicle registries, road vehicle counts, toll station data, traffic models and surveys, the movements of specific vehicles and the purpose of each trip are not registered. This means that road travel emissions cannot be resolved at the individual level as has been done for aviation and maritime emissions.

For international trips, cars, buses, camper vans and caravans can enter Norway at numerous points along the border with Sweden, Finland or Russia, or they can arrive on ferries from Sweden, Denmark or Germany (Fig. 2). Based on the annual report statistics from the ports in Oslo, Kristiansand, Larvik and Sandefjord, 1 224 million cars/buses were ferried to/from Norway and 13.9 million vehicles (excluding lorries transporting goods) crossed the border in 2018 (Samferdselsdepartementet, 2021). Only a small number of vehicles are ferried from Germany and most arrived to Norway via Denmark. Around 92% of on-land border crossings occur between Norway and Sweden (Fig. 2), and the rest occur from Finland (6%) and Russia (2%). The Svinesund Connection (see Svinesund; Fig. 2), where 47% of all vehicles cross the border, is a toll road. Payment data obtained from this, the main crossing site, show that 22.7% of the tolls for small vehicles were paid for through a local payment agreement (Fig. 5). An additional 73.7% used Scandinavian payment options, and the rest constitute the full price paid by vehicles without a chip, assumed not Scandinavian. Another payment dataset from a toll company with stations scattered across southern Norway shows that 2.8% of the passing passenger vehicles are international (the bill is sent abroad). Crossings show a marked peak in July and August with main roads reaching a share of 8.2% international passenger vehicles (Fig. 5). Based on the annual average toll station passing, where international cars make up 2.8% of cars passing, we assume this is equivalent to the part of the road transport they make up on Norwegian

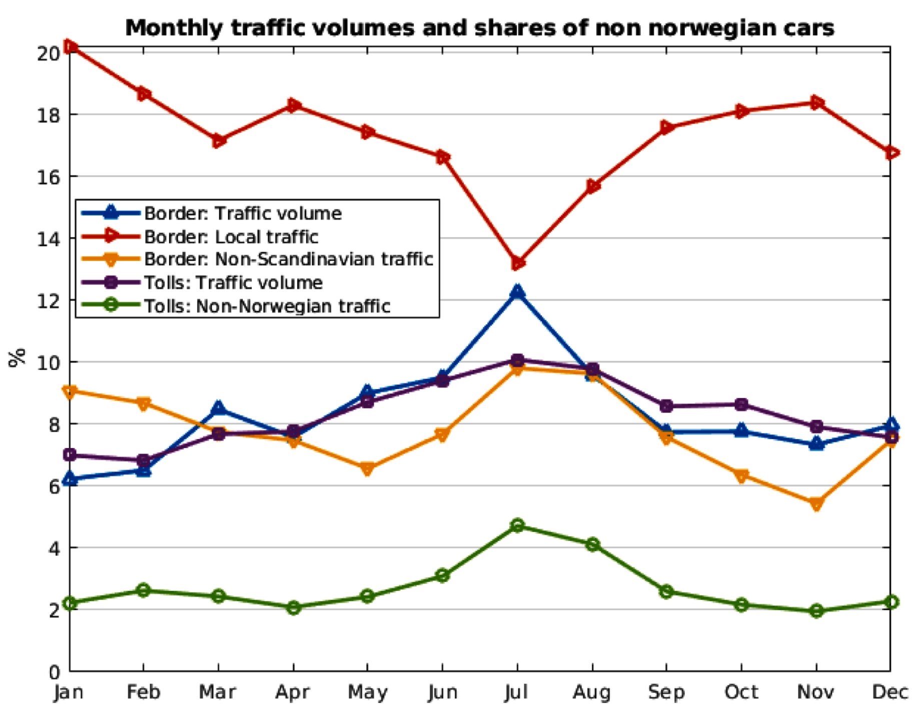

Fig. 5. Monthly traffic shares based on payment method at toll stations. Data from the Border is from Svinesund (shown in Fig. 2) and covers two bridges to Sweden with 60% of the volume of vehicles crossing the Norwegian border. Remaining toll data comes from a toll company with stations scattered over all of southern Norway, located predominantly on main roads.

roads. With the same emission factor as an average Norwegian car, we assume that the annual average percentage of cars this gives a driving distance in Norway of 100 million km and emissions of 120.4 kt of CO_2. This does not include cars rented in Norway. It is often assumed that foreign cars are driven in Norway roughly the distance as is driven by Norwegian-registered cars abroad, although large uncertainties are frequently pointed out (NOEPA, 2019). However, as no other data was available for this study, we applied this assumption.

To calculate Norwegian emissions, we converted the total distance driven into emissions, and distribute emission to Norwegians travelling for holiday and business purposes based on survey statistics. The available surveys distinguish between trips involving overnight stays i) in cabins; ii) in hotels, Bed and Breakfast, etc. (commercial nights); iii) with friends or family; iv) in other types of accommodation; and v) day trips (not relevant for our study). We distinguish vehicle kilometres and passenger kilometres (trips) by the number of people in each transport. In 2018, 429 000 cabins were registered in Norway with an average visitation rate of about 12.4 times per year (Hjorthol et al., 2014). With an average one-way driving distance of 170 km, this makes driving to the cabin 998 million km (5.2% of all kilometres driven by Norwegian private cars). Assuming that all trips are made by cars, with 1.86 persons per car, and 3.6 nights per trip, the total number of nights spent at Norwegian cabins would be 24.8 million. This makes cabin trips similar in volume to commercial tourism nights.

Commercial guest nights, which is reported to Statistics Norway by hotels, official campsites, bed-and-breakfasts and lodges, total 20.7 million overnight stays by foreign tourists and 23.7 million by Norwegians (SSB, 2021b). Driving distance to and from commercial nights can be calculated based on the number of trips as well. For Norwegian tourism, 74% of trips are done by car but, as trips to cabins and to other accommodation are included in survey statistics, cabin trips must be subtracted from the 18.9 million total of domestic trips with at least one night. We calculated 6.9 million to be trips to the cabin. Of the remaining 12 million trips to commercial accommodations, 56% are then by car (having subtracted cabin trips), which gives 984 million vehicle km (5.1% of private car kilometres) based on an assume travelling distance of 250 km. All business trips are assumed to be to commercial accommodation, which makes up one third of commercial accommodation trips with at least one overnight stay. With 14% of all trips to commercial accommodation being done by car for the purpose of business, the same average driving distance as for leisure, gives a total of 250 million km driving distance, or 0.7% of the vehicle kilometres driven for business purposes. Our estimate is then that 15.6% of the total passenger car traffic in Norway has the purpose of tourism, including holidays and business. This is equivalent to 645 kt CO_2 (Table 1). This number does not include the use of rental car or taxis.

The largest emissions from rail travel in Norway are probably related to cancelled trains being replaced by buses. Most of Norway's trains are electric, and diesel trains are limited to a few specific lines. Though the average passenger travel distance on trains was 50 km in 2018 (SSB, 2021b), a crude assumption is that tourists travel a similar length as by car (250 km). That would imply Norwegians on holiday travelled 170 million km by train, or about 4% of all passenger kilometres on railroads (excluding metro and suburban trains), which would make train emissions negligible (Table 1), and more data is needed to accurately assess tourists' share on railroads.

The Norwegian vehicle registry makes no distinction between long-distance coaches and city/suburban buses in regular traffic. Based on a toll station sampling in July 2018, 2 010 long-distance buses registered outside Norway were operating within Norway; for comparison, 1 500 Norway-registered buses were used in domestic coach operations (Stakeholder, 2019). However, foreign-registered coaches mainly operate during summer (Stakeholder, 2019) and are probably fewer in other seasons. This calls into question the value of data collected in July for assessing their contribution to total emissions. As for trains, assuming the same per-trip distance, Norwegians make 4% of their trips on bus. This makes a total passenger kilometre of 98 million km, equivalent to 17% of passenger kilometres on long-distance buses. In the traffic model NERVE (Weydahl et al., 2018), 58% of 2018 CO_2 emissions from buses are in non-urban areas, which can be used as an approximation for long-distance buses. Based on this, we attribute 10% of bus emissions (35 kt CO_2; Table 1) to Norwegian tourists on buses in Norway.

3.5. Total transport emissions

Tourism-related travel as a whole employs all modes of transport. Table 1 shows the total CO_2 emissions from transport of tourists to, from and within Norway in 2018: about 8 530 kt CO_2. Where possible, the distribution of emissions for Norwegian and international tourists travelling for business and holidays is shown. The most emission-intensive sector is aviation, where Norwegian passengers emit 3 573 kt CO_2, when travelling for business (760 kt) or holidays (2 813 kt). Similarly international passengers emit 2 220 kt, with 669 and 1 551 kt CO_2 for business and holiday trips, respectively.

Maritime tourism in the second most intensive emission source, and within waterborne transportation, we distinguish between ferries and cruise ships. We assigned emissions to the passengers rather than to the country where the fuel was sold, and as results we obtain that international ferries release more than half of their emissions outside Norwegian territory. Thus for ferries the same is true as for aviation, that most emissions by Norwegian passengers happen outside Norwegian reporting obligations. For cruises on the other hand most emission happens within Norway but are not by Norwegian passengers. The total net transport emissions, i.e., emissions attributed to Norwegian passengers minus those attributed to international passengers visiting Norway, is 1 602 kt CO_2 (Table 1). This shows that Norwegians, as consumers, are responsible for significantly higher emissions than international travel to and in Norway. Thus, when viewed from a consumer perspective, Norwegian tourism emits significantly more CO_2 than when viewed from a producers or market perspective.

In Table 2 we have compiled the total distance travelled by each means of transport, emission factors, and the average or distance travelled by each passenger. Considering the huge number of kilometres people travel by air (Table 2), the total emissions from aviation are mostly a testament to how many and how far people travel by air compared to other means of transport, as aviation does not have high

Table 2

Movement of tourists (*Pass* = Passenger; *Gm* travel distance in $10^9 m$) in 2018 by different transport modes with associated average emission factor. For emission factors, averages are calculated as total emissions (g of CO_2 per km) divided by total passenger kilometres (*pkm*). The average trip length is in some cases inferred from our own assumptions (e.g., car, bus, train). For aviation and ferries, we assume two-way travel and include both legs of the journey when calculating average passenger travel distance. For cruises, trip length is inferred from AIS data on total distance travelled / unique passengers. Ferry (p) represents the emission factor for only passengers, Ferry (c) the emission factor for only cars on a ferry, and Ferry (p+c) is averaged over both. Camper trip length is obtained by assuming a rate of 12.4 (same as cabins) trips per year. *For these calculations, connecting flights are not considered.

Transport	Pass (Gm)	gCO_2km^{-1}	gCO_2pkm^{-1}	Avg Length	CO_2trip^{-1} (kg)
Car	10 156	123	66.1	590	39.0
Aviation*	46 037	-	92.6	2400	222.2
Cruise	2 727	-	243.8	1600	390.1
Int. Ferry(p)	3 904	-	95.2	696	66.2
Int. Ferry(c)	924	-	586.0	696	407.8
Int. Ferry (p+c)	4 828	-	189.0	696	131.5
Camper	631	285	129.5	933	120.8
Bus(coach)	-	708	35.4	500	17.7
Train	-	-	-	500	

emission per passenger kilometre (*pkm*). Cruise ships have the highest emission factor, but the emission factor from ferries is of similar magnitude when one also takes into account the transport of cars. Table 2 reveals a wide range of both emission factors ($gCO_2\ pkm^{-1}$) and CO_2 emissions per transport modes, as well as important differences in the average trip length and emissions per trip. It must be borne in mind that Table 2 does not compare a single specific trip under different transport modes, but rather the differences in the average type of travel they represent. The emission factors ($gCO_2\ pkm^{-1}$) further depend on how many people share the same transport mode, and therefore emissions; this is not primarily determined by the tourist, but by the passenger load factor.

3.6. Emission reductions due to COVID-19

Fig. 6 shows emissions from tourists' travels in 2018, 2019 and 2020, and from the most relevant transport modes, i.e., aviation, cruises, ferries and road transport. All modes of transport show a seasonal pattern with a peak in July and August both in 2018 and 2019. The strongest seasonality is for large cruise ship traffic (GT>5000), which visit Norway mostly in June-September. Road traffic also has a marked peak in July, related to summer holidays, and a less marked one in March/ April, related to Easter Week holidays. Emissions in 2019 increase by 3% relative to 2018, mainly driven by cruise ships and road emissions. Emissions in January and February 2020 were relatively similar to the same months in 2018 and 2019. In March 2020, when the COVID-19 pandemic hit Norway, however, emissions dropped markedly. This decline corresponds to the implementation of policies to reduce the spread of COVID-19, and that affected the movement of Norwegians and the entrance of travellers into Norway. For instance, on March 14, the Norwegian border was closed for incoming travellers with the exception of those from Sweden and Finland, and on March 19, overnight stays outside the municipality of residence were prohibited, including stays in private holiday houses and cabins. Restrictions started to ease gradually in May, and from June 15, measures were significantly eased. Nordic countries opened for travellers, with restrictions to travellers from regions with high infection rate. In the summer of 2020, higher levels of mobility were possible, although new waves of infection prompted implementation of new and more lasting measures and restrictions, especially on international travel.

Different modes of transport show large differences in how their 2020 emissions changed relative to previous years (Fig. 6 and Fig. 7). Initially, aviation and cruises experienced strong emission reductions in March 2020, and both sectors slowed to a near standstill. Compared to previous years, emissions from aviation were reduced more than 80% in April, May and June of 2020; thereafter, monthly emission reductions were between 60 and 70% until the end of 2020 (Fig. 6). Whilst European and international aviation experienced the strongest decrease, the reductions in domestic aviation were significantly smaller (Fig. 7). CO_2 emissions from cruise ships showed a similar decrease to those from aviation (Fig. 7), and although cruise traffic was slower to react, their emission reductions were also above 80% between May and September (Fig. 7). Emissions from international ferries show smaller decreases, at around 20% from April to June, then they recovered slightly and briefly in July/August (Fig. 7). Several of the international ferries were eventually cancelled, whereas domestic ferries continued operating, albeit at lower intensity than before the COVID pandemic.

Road traffic emissions associated with tourism show a similar pattern to those observed for the previously mentioned sectors. However, in July 2020, emissions were at similar levels to those in July in pre-COVID years. July is the main summer holiday month in Norway and, in 2020, the country experienced a major increase in domestic tourism due to the restrictions on travel abroad (Fig. 6 and 7). For instance, the number of Norwegian tourists on domestic holiday trips in 2020 was 6.41 million, versus 5.01 million in 2018 and 3.95 million in 2019 (SSB, 2021b). Total CO_2 emission reductions from transport-related tourism due to the COVID-19 pandemic were estimated to be around 60% from the end of March 2020, when policy measures were set in place, until the end of the year (Fig. 7).

4. Discussion

An important objective of our study is to identify the sub-sectors to prioritise when designing measures towards low-emission tourism in Norway. In that way, this knowledge provides solid background for policy makers and local tourist operators for the development of sustainable tourism market strategies. Therefore, a bottom-up approach was employed that enabled detailed consideration of factors related to activities that result in emissions, e.g., transport mode technology differences, distance of individual trips, specific passenger load factors and

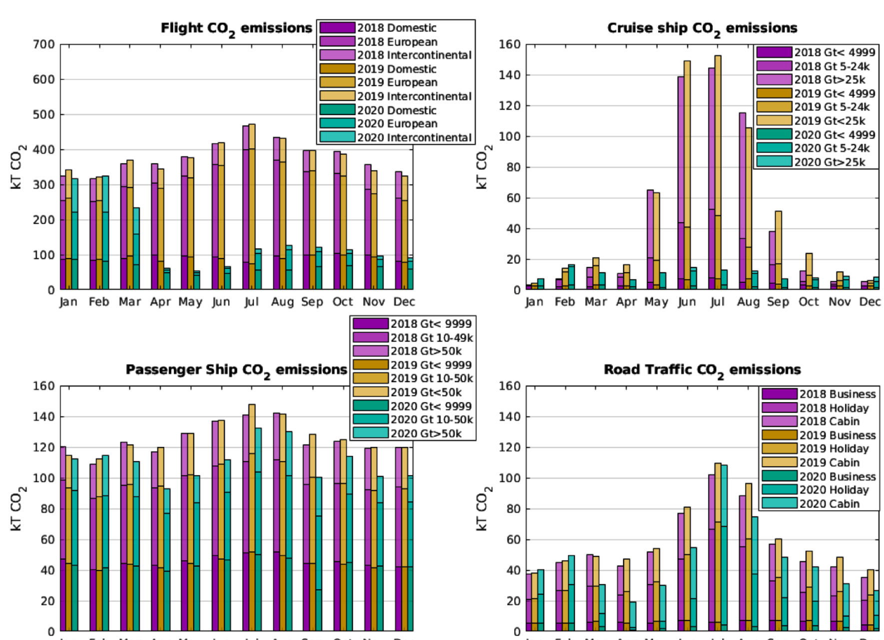

Fig. 6. Monthly CO_2 emissions from aviation (top left), cruise ships (top right), Passenger ships (bottom left) and road traffic (bottom right) in 2018, 2019 and 2020.

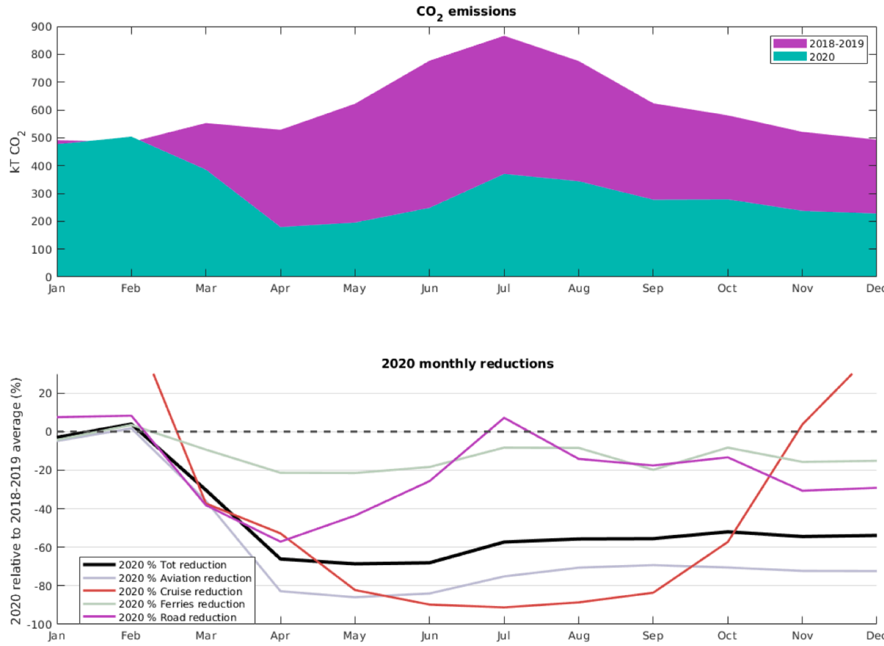

Fig. 7. Monthly CO_2 emissions from all sectors in 2018–2019 and 2020 (top) and monthly CO_2 emission reduction in 2020 compared to emissions in 2018 per sector (coloured lines) and total emission reductions (black line).

detailed emission factors. This type of approach is considered more accurate than others where emissions are derived from ancillary information (López-Aparicio et al., 2017).

There are several sources of uncertainty in our study. Some parts of tourists' trips are left unaccounted for, trips before embarking on the first flight. Similarly, the local transport and activities of Norwegian travellers while abroad are not considered. However, emissions from these presumably short trips make up a small percentage of transport emissions. Passengers on flights, ferries and cruise ships are generally well accounted for, travel distances are known, and the trip purposes are available through surveys. To some extent, this is also true for travel by train. However, the tourist's movement on land is less well tracked. We find that such travel is hard to assess with precision, as there are several factors with large variability, which lead to uncertainty. The actual emissions of a road trip may be well accounted for. However, the total number of trips, average trip length and passenger capacity factor for road transport is not well known, and highly uncertain assumptions had to be made. We have used all available information to make as good assumptions as possible to present a complete picture that includes also road transport. Our estimate that 15.6% of the total passenger car traffic in Norway is for the purpose of tourism is the only available estimate to date.

The principle of producer responsibility is in line with the Kyoto Protocol (UNFCCC et al., 2009), where emissions are calculated based on activities within the borders of a country. On the other hand, calculating emissions at the level of the consumer clarifies the carbon footprint, and enables individual decisions that could lead to more climate-friendly economic development. The principle of common but differentiated responsibility is embraced by the Paris Agreement (UNFCCC, 2015), which acknowledges the individual's responsibility and capacity for carbon mitigation in light of national circumstances. Our approach reflects the direct CO_2 emissions from a consumption perspective, and specifically from the consumption of transport-related services within tourism. In addition, the selection of sub-sectors, i.e., residents versus international tourists visiting Norway, allows us to provide essential information on the allocation of responsibilities. The advantage of tourism passenger based accounting is that international emissions are not assigned to a country but to the passengers (consumers). In that way it is up to society to take on the responsibility and for the tourist industry to shift towards low emission consumer markets.

UNWTO (2008) concluded that transportation is the main source of CO_2 emissions, and contributes up to 75% of total CO_2 emissions of the global tourism industry. Therefore, transportation is the most important sub-sector of emissions within tourism. Moreover, as established by Gössling (2013), emissions from tourism can exceed official emissions reported to the UNFCCC for some countries. In our study, total transport CO_2 emissions from Norway's tourism are 8 530 kt, which is equivalent to 19% of the anthropogenic CO_2 emissions reported by Norway (i.e., 43 817.66 kt CO_2). The total CO_2 emissions obtained in this study are more than double the emissions found in a recent report on Norwegian tourism (Thompson, 2019), but similar to those reported for countries such as Sweden, Germany and The Netherlands (e.g. De Bruijn et al., 2013; Gössling, 2013; Schmied et al., 2008). However, differences between the methodologies employed to calculate emissions make any direct comparison difficult. A main reason our estimate is higher than that previously provided for Norway is that our study considers emissions for the entire trip, including connecting flights, which have a strong influence on total emissions for long-haul travel, whereas emissions reported in Thompson (2019) are based on fuel sales, as is official reporting. In addition, cruise ship and ferry emissions from tourism previously reported for Norway are limited to those associated with the shipping activity inside the Norwegian EEZ, and therefore do not represent the tourists' entire trips. The results from our study show that 20% and 50% of cruise ship and international ferry emissions, respectively, occur outside the Norwegian EEZ. This indicates that considering the entire trip has a strong influence on the emission estimates.

The comparison between studies published in the literature is not simple. The reason is that the number of emission sub-sectors or transport modes considered varies, as well as whether the accounting method considers only direct or also indirect emissions. Moreover, different types of methods are used to estimate emissions from tourism activity and its related transport, yielding variable results. One of the most common ways to account for emissions from tourism is the Tourism Satellite Account (TSA). The TSA is an internationally accepted framework developed by the UNWTO in collaboration with other organisations to measure the impact of tourism on national economy. The TSA is based on estimating tourists' spending on products and services; subsequently, these expenditures are translated into tourism's contribution to value added and employment. Some studies have estimated tourism's emissions based on TSA by assuming that the same share it contributes to value added and employment can be used to determine its share of emissions of GHGs or other pollutants from a production perspective (e.g. Perch-Nielsen et al., 2010; Russo et al., 2020). For Norway, assuming a direct correlation between economic value generation and emissions would give significantly lower emissions from tourism. Methods based on TSA do, however, allow the comparison across studies, despite limitations on the validity of emissions calculations. Other studies combine TSA with input-output approaches (Cadarso et al., 2015; Dwyer et al., 2010; Li et al., 2019), which provide a more holistic carbon footprint overview of activities within a national economic system. These types of approaches are beneficial when performing environmental impact and cost-benefit analysis. Dwyer et al. (2010) selected two approaches to estimate tourism-related emissions, a production approach and an expenditure approach. According to these authors, tourism contributes between 3.9 and 5.3% of total industry GHG emissions in Australia.

Our results indicate that around 57% of transport related emissions from tourism are associated with Norwegians travelling for holidays or business, nationally or internationally. Under the principle of consumer responsibility (Boitier, 2012), Norway is therefore a net exporter of tourist emissions and tourist travels by Norwegians alone account for 11% of the official Norwegian emissions. For comparison, Åkerman (2012) estimated that just the international travel by Swedish residents accounts for 11% of total Swedish emissions (including international transport), though Swedish CO_2 emissions per capita are about half of Norway's. Gössling and Hall (2008) estimated that tourism accounted for approximately 11% of Swedish CO_2 emissions in 2000–2001, and projected the share to grow to 16% by 2020. The authors considered all tourism-related transport in Sweden (excluding cruise ships), and emissions associated with accommodation and activities, but excluded those from Swedes travelling abroad. The comparison with our results is not simple, as the approach followed by Gössling and Hall (2008) (i.e., bunker- fuel) assigns responsibility for emissions to those countries where the fuel is sold, whereas our estimates allocate emissions to the tourist's country of origin.

Nordic countries routinely rank as the most sustainable countries in the world (ACCIONA, 2021; Robeco, 2021). With an ambitious emission reduction plan to achieve climate neutrality by 2030, the accounting in Norway's climate plan relies on production-based emissions that occur within the country border. However, the results from our study show that most tourism-related fuel consumption by Norwegians is related to international aviation and navigation, and thus falls outside of both Norway's efforts to reduce emissions and its reporting obligations. Our results show also that the largest share of emissions is due to residents travelling to distance holiday destinations. This is in line with previous studies that established that socio-economic development and household income are main driving factors for high CO_2 emissions from transportation (Yang et al., 2015; Wang et al., 2017; Yang and Zhou, 2020), as Norway's average household income is above OECD average. The results from our study are relevant for behavioural awareness in line with the country sustainability goals.

Aviation is the cornerstone of the international tourism industry. Therefore, understanding the emissions associated with, and the contribution of different tourism sub-sectors is essential to chart a path towards low-emission tourism. In our study, aviation is the largest source of CO_2 emissions from transport of tourists, followed by maritime and road transport. This is in agreement with previous studies. Åkerman (2012) estimated that 92% of the CO_2 equivalents from international travel by Swedish residents is from air travel. In the compilation of studies carried out by Gössling (2013), the share of emissions associated with air travel varies between 33 and 69% of total tourist emissions, and our study has for Norway 58%. However, most of the studies take into account also other emission sectors than transport, i.e., accommodation, attractions and activities, therefore they would be expected to report somewhat higher shares than ours, as we only include transport emissions. Similarly, Aamaas and Peters (2017) calculated the climate impact of Norwegians travelling domestically and abroad, considering also other relevant GHGs and climate forces than CO_2. They concluded that air transport is responsible for more than 80% of the warming in the first year after emissions, and the share is reduced to 33–47% after 100 years depending on the emission metric choices to describe the Global Warming Potential.

Even though aviation is the most emission intensive transport mode, our study also shows that these emissions are driven by the large number of people being transported long distances, and not that the emission factor per person kilometre is high. It is rather cruise ships and international ferries transporting cars in addition to the passengers, that show the highest emission factor per passenger kilometre.

Emissions are dominated by trips for holiday purposes, although our results may underestimate emissions from long-haul trips for work purposes, where first class and business class are more common than for domestic or short-haul European flights. Bofinger and Strand (2013) estimated that the carbon footprint of a premium-class flight is three times (business) and nine times (first class) larger than a flight in economy class. Even though we do not differentiate flight travelling classes, the difference in emission intensity of holidays compared with business trip is consistent with previous studies. Hille et al. (2007) analysed energy consumption in Norway, covering a long range of activities related to work, professional time and free time. They found that holiday journeys were the most energy-intensive form of consumption during leisure time in Norway. Based on our results, the largest CO_2 emissions are associated with holiday trips, especially to warm countries such as Spain, Thailand, Greece and Turkey. Business trips constitute 18% of the total transport-related emissions from tourism. These results indicate that a stronger focus on reducing holiday trips is required. According to (Gössling et al., 2019), there is a weak correlation between "want to travel" and "need to travel", and defining needs is an essential step in making adjustments after the COVID-19 pandemic and in planning future pathways. In addition, the need to travel must be defined specifically per purpose of the trip. Due to the COVID-19 pandemic, business travel has essentially stopped, and its potential continuation after the pandemic is debatable. However, based on our results, holiday trips are a much larger source of emissions and also need to be reduced to obtain a meaningful reduction of emissions.

Travellers' emissions depend on the travelled distance, the passenger load factor and transport-mode based emission factors. These variables will determine our individual emissions as travellers (Table 2). This study reveals that during the COVID-19 pandemic, overall CO_2 emissions from tourism in Norway were substantially reduced. However, the individual traveller's emissions in 2020 can be significantly higher than in previous years. For instance, the average passenger load factor in aviation was significantly lower in 2020 than in previous years, thus increasing emissions per passenger for each flight.

An effective way of reducing emissions is by targeting specific subsectors or markets that contribute strongly to total emissions. Within the tourism industry, marketing strategies can contribute towards reducing emissions. For instance, strategies can target markets that involve short-haul trips and domestic tourism, or promote long stays versus frequent short trips. The net emissions obtained in our study indicate that travel by Norwegian residents, especially holiday travel, is the main source of Norway's travel emissions. Targeting this sub-sector could lead to large emission reductions. Changes in destination, such as choosing a Scandinavian rather than a European destination, or the Canary Islands rather than Thailand, have been reported as a useful measure to reduce emissions in the Nordic context (Kamb et al., 2020). According to Peeters and Schouten, 2006, there are four options to reduce emissions from tourism: i) reducing GHG emissions per pkm; ii) shifting towards transport modes with lower GHGs emissions (e.g., from air/water to land); iii) reducing travel distances by promoting domestic and short-haul markets; iv) extending the length of stay. Based on the results from our study, shifting transport mode to land may have undesired consequences as road transportation is also an intensive emission source. Lenzen et al. (2018) stated that mitigation strategies such as encouraging travellers to choose short-haul trips and to fly less yield limited success, and carbon taxes or carbon trading schemes may be required.

5. Conclusions

In this study we have presented CO_2 emissions from tourists travelling from, to and within Norway, including both domestic and international trips for both holidays and business. Emissions in 2018 were analysed in detail, as were the changes in emissions in 2020 after the onset of the COVID-19 pandemic. Tourism emitted 8 530 kt CO_2 in 2018 associated with the transport of passengers. This is equivalent to 19% of the emissions reported by Norway to UNFCCC for the same year, and travel by Norwegian residents alone contributes 11%.

The highest CO_2 emissions from tourism was calculated to be from aviation, with 71% of total CO_2 travel emissions. This is followed by waterborne navigation (ferries and cruises; 21%) and road transport (private cars; 8%). Aviation is the largest contributing sub-sector, mainly owing to the large number of travellers and the long distances travelled. The highest emissions factors per passenger kilometre were found for cruise ships and ferries transporting cars in addition to passengers.

Total CO_2 emissions are dominated by Norwegians travelling for holidays, which contributes 47% of total emissions. The largest share of Norwegian travel emissions is from international aviation (2 286 kt CO_2) to warm destinations such as Spain, Greece, Thailand and Turkey. Our study highlighted the importance of considering connecting flights when estimating emissions from aviation-related tourism. In our study, connecting flights represent 30% of the emissions from international aviation, and this part is commonly unaccounted for in other studies on tourism emissions.

International tourists who visit Norway make for 3 273 kt CO_2, of which 2 220 kt is from aviation and 949 kt from waterborne navigation. The tourist market with highest emissions is Germany with 441 kt CO_2 of which 15%, 48% and 37% come from aviation, cruises and ferries, respectively. Passengers from USA cause the second highest emissions, mainly from aviation (349 kt CO_2) and cruise ships (56 kt CO_2). Of the total tourist emissions, holiday travel contributes 78%. The net emissions, calculated as the difference between emissions from Norwegian residents and those from tourists visiting Norway, are 1 602 kt CO_2, placing the responsibility for transport emissions from Norway's travel on Norwegian residents.

Our study shows that officially reported emissions, limited to the countries territory and based on fuel sales, are not suitable for accurately estimate transport CO_2 emissions related to tourism. The dissagregation of emissions per market following a consumer based approach gives a marked redistribution of emission responsibility. Norwegian residents travelling behaviour involves the highest share of emissions. This is driven by frequent holiday trips to popular tourist destinations. A consumer based calculations at global scale would shift the responsibility of emissions by tourists to wealthy nations. Our results can also support the development of marketing strategies to attract low emission tourist markets by local tourist operators. A shift from international to domestic holiday trips as happened during the pandemic resulted in 60% emissions reduction.

In 2020, restrictions were put on travel due to the COVID-19 pandemic, leading to a reduction in mobility. As a consequence, CO_2 emissions experienced a massive reduction of 60%, which was sustained from late March to at least the end the year. Aviation and cruise ship emissions had the largest emission decreases, whereas road transport emissions in July 2020 were at the same level or even higher than in pre-COVID years. The lack of decrease or even at times increase in tourist emissions from road traffic was due to an increase in domestic tourism in Norway. The lack of international tourism due to the COVID-19 pandemic, and Norwegian residents' shift to domestic tourism, made the overall drop in emissions from the tourism industry the largest for any industry in Norway.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowlgedments

This study was originally financed by Innovation Norway (CO2RISM project) and supported by the SIS EMISYS project (Emission system for climate gases, air pollutants and other environmental contaminants). Special thanks to Ingunn Sørnes (Innovation Norway) for her support, Torolf Holte (AVINOR AS) for sharing the databases from AVINOR and his support interpreting the data. Thanks to Einar Bjørshold and colleagues from the Norwegian Coastal Administration for providing additional data on movement and emissions from passenger vessels and cruise ships in and coming to Norway. Thanks to Svinesundsforbindelsen and Dan Isak Kveta (Vegfinans) for providing payment data from the passing of vehicles through the toll systems.

Supplementary material

Supplementary material associated with this article can be found, in the online version, at 10.1016/j.envadv.2021.100104

References

Aamaas, B., Peters, G.P., 2017. The climate impact of norwegians' travel behavior. Travel Behaviour and Society 6, 10–18.
ACCIONA, 2021. What puts nordic countries at the top of the sustainability rankings? https://www.activesustainability.com/sustainable-development/nordic-countries-top-sustainability-rankings/.
Åkerman, J., 2012. Climate impact of international travel by swedish residents. J Transp Geogr 25, 87–93.
AVINOR, 2019. Reisevaner på fly 2019. AVINOR. https://avinor.no/contentassets/b3f78317709344549da26fa3ebda6977/avinor-reisevaneundersokelsen-2019.pdf.
Blomstervik, I., Dahl, H., Dehli, Å.L., Plischewski, M., Lotte, Ø., 2015. Hurtigruten ASA. B.S. thesis.
Bofinger, H., Strand, J., 2013. Calculating the Carbon Footprint from Different Classes of Air Travel. The World Bank, Policy Research Working Paper 6471.
Boitier, B., 2012. *co*2Emissions production-based accounting vs consumption: insights from the wiod databases. In WIOD Conference Paper, April.http://www.wiod.org/conferences/groningen/paper_Boitier.pdf
Brekke, A., Saxegård, S.A., Nilsen, M., Tellnes, L.G., 2018. Hvor klimavennlig er det å ta med seg hytta på ferie. https://norsus.no/wp-content/uploads/or_25_18_klimagassregnskap_bobiler.pdf.
Cadarso, M.-Á., Gómez, N., López, L.-A., Tobarra, M.-Á., Zafrilla, J.-E., 2015. Quantifying spanish tourism's carbon footprint: the contributions of residents and visitors: a longitudinal study. Journal of Sustainable Tourism 23 (6), 922–946.
CLIA, 2018. 2018 Europe Market Report. Cruise Lines International Association.https://cruising.org/-/media/research-updates/research/final-market-report-europe-2018.pdf
De Bruijn, K., Dirven, R., Eijgelaar, E., Peeters, P., Nelemans, R., 2013. Travelling Large in 2011. the Carbon Footprint of Dutch Holidaymakers in 2011 and the Development since 2002. NHTV Breda University for Applied Sciences.
Dubois, G., Ceron, J.P., 2006. Tourism/leisure greenhouse gas emissions forecasts for 2050: factors for change in france. Journal of Sustainable Tourism 14 (2), 172–191.
Dwyer, L., Forsyth, P., Spurr, R., Hoque, S., 2010. Estimating the carbon footprint of australian tourism. Journal of Sustainable tourism 18 (3), 355–376.
Eggleston, H., Buendia, L., Miwa, K., Ngara, T., Tanabe, K., 2006. 2006 Ipcc Guidelines for National Greenhouse Gas Inventories.
Epinion, 2019. Den nasjonale reisevaneundersøkelsen 2018: nøkkelrapport.
Eurocontrol, 2019. Small Emitters Tool (SET) - Emissions Calculator. Eurocontrol. https://www.eurocontrol.int/publication/small-emitters-tool-set-2019.
Eurocontrol, 2020. COVID19 Impact on European Air Traffic EUROCONTROL - Comprehensive Assessment. Eurocontrol.https://www.eurocontrol.int/sites/default/files/2020-04/covid19-eurocontrol-comprehensive-air-traffic-assessment-14042020.pdf
Gössling, S., 2013. National emissions from tourism: an overlooked policy challenge? Energy Policy 59, 433–442.
Gössling, S., Hall, C.M., 2008. Swedish tourism and climate change mitigation: an emerging conflict? Scandinavian Journal of Hospitality and Tourism 8 (2), 141–158.

Gössling, S., Hanna, P., Higham, J., Cohen, S., Hopkins, D., 2019. Can we fly less? evaluating the 'necessity'of air travel. Journal of Air Transport Management 81, 101722.

Gössling, S., Scott, D., Hall, C.M., 2015. Inter-market variability in co2 emission-intensities in tourism: implications for destination marketing and carbon management. Tourism Management 46, 203–212.

Graver, B., Rutherford, D., Zheng, S., 2020. Co2 Emissions from Commercial Aviation: 2013, 2018, and 2019. https://theicct.org/publications/co2-emissions-commercial-aviation-2020.

Hall, C.M., 2014. Tourism and Social Marketing. Routledge.

Havbase, 2021. Ship Traffic Data from the Norwegian Coastal Administration. Norwegian Coastal Administration.https://www.havbase.no/

Hille, J., Aall, C., Klepp, I.G., 2007. Miljøbelastninger fra norsk fritidsforbruk–en kartlegging. Norway, Vestlandsforsking and SIFO.

Hjorthol, R., ystein Engebretsen, O., Uteng., T.P., 2014. Den nasjonale reisevaneundersøkelsen 2013/14: nøkkelrapport. Transportøkonomisk institutt.

Howitt, O.J., Revol, V.G., Smith, I.J., Rodger, C.J., 2010. Carbon emissions from international cruise ship passengers' travel to and from new zealand. Energy Policy 38 (5), 2552–2560.

Høyer, K.G., 2000. Sustainable tourism or sustainable mobility? the norwegian case. Journal of Sustainable tourism 8 (2), 147–160.

IATA, 2014. Recommended Practice 1678 - CO_2 Emissions Measurements Methodology. International Air Transport Association.https://www.iata.org/contentassets/34f5341668f14157ac55896f364e3451/rp-carbon-calculation.pdf

ICAO, N., 2017. ICAO Carbon Emissions Calculation Methodology. International Civil Aviation Organization.https://www.icao.int/environmental-protection/Carbonoffset/Pages/default.aspx

IN, 2019. Nøkkeltall cruise 2017–2018 – En oversikt over norsk cruisenaering. Innovation Norway. https://assets.simpleviewcms.com/simpleview/image/upload/v1/clients/norway/IN_cruiserapport_2018_ORGINAL_LAV_ENKEL_d1ad1204-cca5-41ef-8cfe-c34e241fcd0a.pdf.

Johansson, L., Jalkanen, J., Kukkonen, J., 2017. Global assessment of shipping emissions in 2015 on a high spatial and temporal resolution. Atmos. Environ. 167, 403415.

Kamb, A., Lundberg, E., Larsson, J., Nilsson, J., 2020. Potentials for reducing climate impact from tourism transport behavior. Journal of Sustainable Tourism 1–18.

Kristensen, H.O.H., Hagemeister, C., 2012. Environmental Performance Evaluation of Ro-Ro Passenger Ferry Transportation. Danish information paper for the work in the MEPC committee under The International Maritime Organisation, IMO in London.

Larsson, J., Kamb, A., Nässén, J., Åkerman, J., 2018. Measuring greenhouse gas emissions from international air travel of a country's residents methodological development and application for sweden. Environ Impact Assess Rev 72, 137–144.

Lenzen, M., Sun, Y.-Y., Faturay, F., Ting, Y.-P., Geschke, A., Malik, A., 2018. The carbon footprint of global tourism. Nat Clim Chang 8 (6), 522–528.

Li, L., Li, J., Tang, L., Wang, S., 2019. Balancing tourism's economic benefit and co2 emissions: an insight from input–output and tourism satellite account analysis. Sustainability 11 (4), 1052.

Lin, T.-P., 2010. Carbon dioxide emissions from transport in taiwan's national parks. Tourism Management 31 (2), 285–290.

Liu, J., Feng, T., Yang, X., 2011. The energy requirements and carbon dioxide emissions of tourism industry of western china: a case of chengdu city. Renewable Sustainable Energy Rev. 15 (6), 2887–2894.

López-Aparicio, S., Guevara, M., Thunis, P., Cuvelier, K., Tarrasón, L., 2017. Assessment of discrepancies between bottom-up and regional emission inventories in norwegian urban areas. Atmos. Environ. 154, 285–296.

NOEPA, 2019. Greenhouse Gas Emissions 1990 deldDel- deliIns–2017, National Inventory Report. Norwegian Environment Agency. https://www.miljodirektoratet.no/publikasjoner/2019/april-2019/greenhouse-gas-emissions-1990-2017-national-inventory-report/.

Peeters, P., Schouten, F., 2006. Reducing the ecological footprint of inbound tourism and transport to amsterdam. Journal of sustainable tourism 14 (2), 157–171.

Perch-Nielsen, S., Sesartic, A., Stucki, M., 2010. The greenhouse gas intensity of the tourism sector: the case of switzerland. Environmental Science & Policy 13 (2), 131–140.

Robeco, 2021. Norway is now the most sustainable country in the world. https://www.robeco.com/en/insights/2020/01/norway-rises-to-top-of-country-sustainability-ranking.html.

Russo, M., Relvas, H., Gama, C., Lopes, M., Borrego, C., Rodrigues, V., Robaina, M., Madaleno, M., Carneiro, M., Eusébio, C., et al., 2020. Estimating emissions from tourism activities. Atmos. Environ. 220, 117048.

Samferdselsdepartementet, D.K.N., 2021. Meld. St. 20 Nasjonal Transportplan 2022 deldDel- deliIns–2033. https://www.vegvesen.no/_attachment/2685640/binary/1325907?fast_title=Grensekryssende+infrastruktur+og+transport+-+vedlegg+1.pdf.

Schmied, M., Götz, K., Kreilkamp, E., Buchert, M., Hellwig, T., Otten, S., 2008. Traumziel Nachhaltigkeit: Innovative Vermarktungskonzepte Nachhaltiger Tourismusangebote FÜr Den Massenmarkt. Springer Science & Business Media.

SSB, 2021. Correction of Figures for Sales of Marine Gas Oils and Auto Diesel. Statistics Norway. https://www.ssb.no/en/natur-og-miljo/artikler-og-publikasjoner/correction-of-figures-for-sales-of-marine-gas-oils-an.

SSB, 2021b. Statistics norway. https://www.ssb.no/en/statbank/.

Stakeholder, 2019. Turbussmarkedet i Norge. Ulike konkurransevilkår for norske og utenlandske aktører. Stakeholder.no. https://www.transport.no/dokumenter/2018/rapport-om-turbussmarkedet/.

Sun, Y.-Y., Lin, P.-C., Higham, J., 2020. Managing tourism emissions through optimizing the tourism demand mix: concept and analysis. Tourism management 81, 104161.

Surugiu, C., Surugiu, M.R., Breda, Z., Dinca, A.-I., 2012. An input-output approach of co2 emissions in tourism sector in post-communist romania. Procedia Economics and Finance 3, 987–992.

Tang, C., Zhong, L., Ng, P., 2017. Factors that influence the tourism industry's carbon emissions: a tourism area life cycle model perspective. Energy Policy 109, 704–718.

Thompson, S., 2019. Klimagassutslipp knyttet til norsk reiseliv. NHO Reiseliv.https://www.nhoreiseliv.no/contentassets/e630f86bfe2d4e028f6903d81bce6fd5/klimaregnskap-for-norsk-reiselivsbransje.pdf

UNFCCC, 2015. Paris agreement. Report of the Conference of the Parties to the United Nations Framework Convention on Climate Change (21st Session, 2015: Paris). Retrieved December, 4. HeinOnline, p. 2017.

UNFCCC, 2021. Greenhouse Gas Inventory Data - UNFCCC. United Nations Framework Convention on Climate Change.https://di.unfccc.int/flex_annex1

UNFCCC, U., et al., 2009. Kyoto protocol reference manual on accounting of emissions and assigned amount. Technical Report. eSocialSciences.https://unfccc.int/sites/default/files/08_unfccc_kp_ref_manual.pdf

UNTWO, 2020. International tourist arrivals could fall by 20–30% in 2020. https://www.unwto.org/news/international-tourism-arrivals-could-fall-in-202.

UNWTO, 2008. Climate Change and Tourism: Responding to Global Challenges. United Nations World Tourism Organisation: Madrid, Spain.https://webunwto.s3-eu-west-1.amazonaws.com/imported_images/30875/climate2008.pdf

UNWTO, 2019. Transport-related CO_2 Emissions of the Tourism Sector - Modelling Results. United Nations World Tourism Organisation: Madrid, Spain.https://www.e-unwto.org/doi/book/10.18111/9789284416660

Wang, S., Liu, X., Zhou, C., Hu, J., Ou, J., 2017. Examining the impacts of socioeconomic factors, urban form, and transportation networks on co2 emissions in china's megacities. Appl Energy 185, 189–200.

Weydahl, T., Grythe, H., Wergeland H, T., Hoeyem, H., 2018. Nerve-utslippsmodell for veitrafikk. NILU Report 28/2018.

WTTC, 2010. Climate change: A joint approach to addressing the challenge.

WTTC, 2017. Tourism: global economic impact & issues 2018. WTTC: London, UK. https://wttc.org/Research/Economic-Impact.

Yang, W., Li, T., Cao, X., 2015. Examining the impacts of socio-economic factors, urban form and transportation development on co2 emissions from transportation in china: a panel data analysis of china's provinces. Habitat Int 49, 212–220.

Yang, W., Zhou, S., 2020. Using decision tree analysis to identify the determinants of residents' co2 emissions from different types of trips: acase study of guangzhou, china. J Clean Prod 277, 124071.