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A simulation model to assess emission reduction policies in tourism transport: Case study of the Geiranger fjord UNESCO world heritage site in Norway

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ABSTRACT
Tourism transport may lead to significant air emissions and congestion problems on road networks. This is particularly troublesome for nature-based tourism destinations, as they often are in rural areas with low transportation capacities and vulnerable nature. Tourism transport systems are poorly understood, especially multi-modal systems with land and sea dynamics. In this article, we propose a multi-modal transport model that integrates traffic both at land and sea generated by tourism. The model was built on data from an in-situ questionnaire and validated with traffic counts and video recordings for the Geiranger fjord UNESCO world heritage site in Norway. Following a parliament decision to eliminate emissions from sea traffic, four emission reduction scenarios were explored. Results show that cruise-generated tourist buses may significantly contribute to air emissions and the formation of road congestion and emphasize the necessity of having a holistic approach in analyzing consequences of emission reduction policies for tourism transport. The model may be used in transportation planning and policymaking to assess alternative pathways to sustainable tourism transport.

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Introduction

The acceleration of global warming has intensified the need for emission reduction measures across all sectors. Together with the EU, Norway aims to reduce greenhouse gas (GHG) emissions by 40%, compared to 2005 levels, by 2030 (Meld. St. 41, 2016). Tourism as a sector contributes to 8% of the global GHG emissions (Lenzen et al., 2018). Prior to the Covid-19 outbreak, tourism was growing at an annual average of 4% (OECD, 2020), and although the pandemic dramatically reduced tourism activity in 2020 and 2021, it is expected to recover in a few years, from two to four depending on the country destination (Zhang et al., 2021). This revival provides an opportunity for sustainable transformation of the tourism industry (Sharma et al., 2021). Sustainable tourism may be defined as "tourism that takes full account of its current and future economic, social and environmental impacts, addressing the needs of visitors, the industry, the environment, and host communities" (UNWTO, 2021).

Transportation is a key element for tourism (Kádár & Gede, 2021; Khadaroo & Seetanah, 2008; Law et al., 2019; Mill & Morrison, 2002; Morley et al., 2014; Murphy et al., 2000; Pearce, 1981; Prideaux, 2000; Taplin & Qiu, 1997; Virkar & Prita, 2018) as it provides access to the destination, and allow intra-destination movements (Page, 2009; Prideaux, 2000). Transport may also be the objective for tourists as it facilitates travel along recreational routes (Hall, 2004; Lumsdon & Page, 2004). Like any other type of transport, tourism transport contributes to global air emissions. In general, transport sector emits almost 30% of the greenhouse gas (GHG), of which road transport sector contributed to 72% in 2020 in Europe (EEA, 2021). The tourism transport accounts for a higher share of emissions as 75% of GHG emissions associated with tourism are emitted from transport sector (Scott et al., 2010).

Among different transport modes, the cruise industry has seen a rapid growth over the last decades and has become an increasingly important segment in tourism transport (Sun et al., 2011; Zhen et al., 2018). In 2019, the Norwegian parliament voted to achieve zero emission from sea traffic in the West Norwegian Fjords by 2026, which may strongly influence cruise tourism along the coast (DNV-GL, 2020). Ports are crucial links between sea and land; hence policies modifying the cruise arrivals at the ports directly affect road transport. This triggers the need for utilizing an integrated approach to analyze the consequences of these tourism policies.

In this article, we highlight the importance of having an integrated approach in analyzing emission reduction policies in tourism transport especially where several transport modes are involved in the system. We present a multi-modal transport model to evaluate tourism traffic and associated emissions and congestion points in a protected area under different emission reduction scenarios. The model follows a four-step structure, with extensions to account for

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traffic generated from land and sea-based tourism. It was built on data from tourist visitor statistics, an in-situ questionnaire in 2018 (Babri & Díez-Gutiérrez, 2019) with 915 participants, road network features, and bus operators' routes. It was further validated with traffic counts, ferry ticket sales, and video recordings (Dahl & Meland, 2018) from the same reference year. The model was used to simulate different scenarios for the planning year 2026, thus the number of tourist and scenarios were assumed for that year. Model outputs include traffic flow simulations, emission estimates, congestion points and time-loss for travelers in the land transport network. This enables planners and policy makers to appraise alternative emission reduction scenarios in complex transport systems where there is a dynamic relationship between sea and land transport. The model is applied to a case study of Geiranger fjord in Norway, a UNESCO World Heritage Site to analyze potential scenarios addressing a parliament decision to eliminate emissions from sea-traffic in the area.

In section 2 of this article, existing literature is reviewed, including studies on emissions reduction policies in tourism transport, and studies aiming at developing methods for measuring air emissions associated with tourism transport. Section 3 presents the method and materials, including the case study description. Results are presented in section 4 and further discussed in section 5. Lastly, conclusions and policy implications of this research are gathered in section 6.

Literature review

Emission reduction policies in tourism transport

In coastal destinations, where there is close relationship between coastal and inland areas, the importance of emission reduction policies is emphasized due to the ecosystem's vulnerability (Cavallaro et al., 2017). In some of these destinations, cruise tourists disembark at the port during their trip to further explore the surrounding areas on their own or via organized tourist buses or other mobility solutions, such as car-sharing or bikes (Morfoulaki et al., 2021). This sea-generated land traffic may increase congestion on the road transport network (Calatayud et al., 2022).

Transport modes for tourists vary according to the spatial distribution of tourists and their mobility needs (Duval, 2007). Thus, policies to mitigate consequences of tourism transport must be tailored based on the characteristics of destinations and the relevant transport modes. Cavallaro et al. (2017) summarized sustainable policies in tourism transport into two main categories: (1) policies which promote sustainable transport through improving communication systems with tourists and offering better mobility products, and (2) policies which mainly reduce the need to travel; shifts to more efficient transport modes and improve fuels and vehicle technologies. Although emission reduction policies in tourism transport may lead to lower emission level, a substantial reduction requires major shift in transport modes, distance, and introduction of new low-carbon transport technologies (Dubois et al., 2011) which requires changes in tourism marketing strategies (Gössling et al., 2015; Sun et al., 2020). The role of social and behavioral changes is also highlighted in the literature, pointing out that technological and managerial measures are not sufficient to achieve a climatically sustainable tourism (Gössling et al., 2010).

Gössling et al. (2010) concluded that reducing emissions from tourism is challenging due to incomplete understanding of the drivers of growth in emissions and their complexity and dynamics from many tourism actors. Reluctancy to accept the need for drastic behavioral changes in tourism, misinterpretation of the information in decision making and fabrication of uncertainty in emission reduction measures to justify non-action among tourism industry leaders are considered main barriers to progress on the decarbonization of tourism (Gössling & Scott, 2018).

To effectively reduce emissions from tourism transport, the literature suggests combining different emission reduction strategies (Cavallaro et al., 2017). However, the emission reduction policies are often designed to target one specific aspect without considering the connection between different modes in tourist transport systems. Enforcement to achieve a zero-emission sea transport by Norwegian parliament is an example which targets only one aspect of tourism transport in a coastal area where several transport modes are involved.

Evaluating emission reduction policies in tourism transport

The mobility patterns between everyday trips (domestic behavior) and holidays trips (touristic behavior) differ (Maltese et al., 2021). Thus, developing specific tools to model tourists' mobility behavior and measure emissions from tourism is necessary. This may however be challenging due to lack of data and information on tourist transportation and travel behavior (Gladstone et al., 2013). Transport models could be used to obtain sustainability indicators and predict potential impacts of different transportation projects or policies (Le Pira et al., 2021). Simple transport models have already shown promising results to compute impacts from various transportation scenarios for tourism transport (Díez Gutiérrez et al., 2017) and may be powerful tools to support planning process (Ortúzar & Willumsen, 2011).

Tourism transport at the regional level has been explored both in view of travel modes and routes. The first stream of studies include observations of the acceptance of various policies or the drivers toward the use of more sustainable transport modes for tourists (Aguiló et al., 2012; Lumsdon et al., 2006; Orsi & Geneletti, 2014; Ruiz-Pérez & Seguí-Pons, 2020; Scuttari et al., 2019); analyzing the satisfaction of public transportation within tourists concerning trip motivations, socioeconomic and personal characteristics (Romão & Bi, 2021); estimating the spatial correlation between transportation mode and tourism destinations (Qian et al., 2021); and observing the effects of parking areas for tourist density (Pouwels et al., 2020; Weitowitz et al., 2019). Research focusing on travel routes include identification of traffic volumes at different itineraries based on a map-based questionnaire of visitors using national park roads (Connell & Page, 2008). Díez-Gutiérrez and Babri (2020) used a path size correction logit (PSCL) model to understand the factors for selecting different routes, including socioeconomic, road, and trip characteristics. Mode and route choice were jointly analyzed based on nested logit models in Li et al. (2020).

Previous research has also focused on the spatial distribution of tourists, based on visitor statistics and social big data (Chun et al., 2020), or interviews and GPS data (Edwards & Griffin, 2013). Zyryanov and Myshlyavtseva (2012) developed a tool to assist tourist managers in planning tourism movements based on tourism clusters, defined as areas with tourist flows, events, attraction points, while Castillo-Vizuete et al. (2021) developed a planning tool based on infrastructural objects. Ishikawa et al. (2013) also synthesized a tool for designing alternative tourist routes based on spatial network analysis or for detecting traffic congestion points based on a traffic cellular automation model.

In addition, some studies aimed to model air emissions from tourism transport (Cavallaro et al., 2021; Dubois et al., 2011). An ideal framework to calculate emission from tourism transport include information on the origin and destination of tourists, the routing, transport mode and operational factors, such as occupancy rates (load factors), as well as information on engine types (Scott et al., 2008). However, few studies adopt a holistic perspective of tourist movements including the above-mentioned factors, mainly due to lack of information (Scott et al., 2008). Existing literature furthermore focuses on road transport but lacks models combining road and sea transport, which is useful in addressing tourism traffic in coastal areas where the two transport modes are interconnected (Cavallaro et al., 2017).

Transport models that estimate environmental impacts from transport may use indicators such as average daily traffic (number of vehicles), average kilometers driven per vehicle type, tonnes of GHG emissions, and average time spent under congested road conditions. A common indicator is transport footprint, measured as tonnes of carbon dioxide (CO2) from fossil fuel combustion. In Chi and Stone (2005) and Martín-Cejas and Ramírez Sánchez (2010), this footprint was computed for road segments, while Chi and Zheng (2013) further expanded these road segments based on network analysis and Kriging methods. Previous studies have also assessed environmental impacts from transportation (Chen et al., 2018; Lee & Brahmasrene, 2013; Michailidou et al., 2016). One of the more comprehensive models are found in Martín-Cejas (2015) where road dimensions, traffic volumes, type of vehicles, and vehicle fuel efficiency are used to estimate CO2-emissions. While GHGs are important in the global context, local emissions of particles and gases are also critical to provide a complete profile of adverse effects from traffic. This is particularly important for traffic in tourist destinations where both residents as well as visitors may experience health effects due to exposure to pollutants. In the model presented in this article, we include emissions of CO2, nitrogen oxides (NOx) and particulate matter (PM) from tourism traffic.

The research presented in this paper contributes to the existing body of knowledge by developing a model to improve understanding of tourism transport based on travel behavior and preferences including, origins, transport modes, routes, destinations, and attraction points. Moreover, it permits analyzing emission from tourism transport and potential traffic volume dynamics resulting from varying external conditions, such as fluctuations in sea traffic, thereby improving knowledge of the connection between sea and land transport for tourism.

Methodology

To develop the model which include information on origins, transport modes, routes, destinations, and attraction points, we have chosen a case study which is presented in this section. We further elaborate on the process of data collection and how the data from different sources are incorporated into an integrated model.

Case study area and scenarios

Geiranger is a tourist village in the western part of Norway located at the end of Geiranger fjord. The fjord and surrounding area was inscribed on the UNESCO World Heritage list in 2005 and is considered among the top 10 tourist destinations in Norway (Visit Norway, 2021a). The village has 250 inhabitants and welcome approximately one million tourists in a normal year (Yttredal et al., 2019). Figure 1 shows the location of the Geiranger center, the UNESCO-protected area, the studied area, and the traffic counting stations.

Geiranger center can be visited by land from the north, west, or south, or by the sea through the Geiranger fjord. The north and west accesses include ferry connections, while the south road access is a conventional road connection. Only the north access is open all year, while the other two are closed between October and April/May due to snow and weather conditions in winter. The primary peak season for Geiranger port is between June and August when it receives several cruises and express ferries. In 2018, more than 180 cruises docked at the port (Yttredal et al., 2019). As with other cold climate destinations, this area suffers seasonality problems (Baum & Hagen, 1999). More than 80% of the tourists visiting Geiranger arrives between June and August (Yttredal et al., 2019), as around 800,000 tourists enter the area by sea and land during these three months congestion and emission problems arise.

In 2018, the Norwegian parliament voted to set a zero-emission requirement from sea transportation in the UNESCO world heritage sites by 2026. This generated a need to understand transportation system implications for various scenarios. The four scenarios developed through expert judgment in workshops and interviews are specified in Table 1. The daily amount of cruise passengers entering the study area under each scenario is based on estimates provided by the cruise industry and local port authorities. These were provided based on historical data and port capacities. It was estimated that some of the tourists took a roundtrip between the cruise port and Geiranger by bus.

Figure 1. Location and traffic counts.

Table 1. Future scenarios definition (year 2026).

	Scenario	Description	Average daily number of cruise passengers arriving at the area in the peak season	Percentage of cruise-passengers transported to Geiranger
Reference	Geiranger – Business as usual	Cruise ships continue to arrive at Geiranger. Passengers do local sightseeing by bus.	3500	–
1	Hellesylt- Blue corridor	Cruise ships arrive at Hellesylt (node 17 in Figure 4). Passengers are further transported to/from Geiranger with bus.	3500	50%
2	Stranda- new port	A new port will be developed in Stranda (node 16 in Figure 4). Cruise ships arrive at the new port and passengers are further transported to/from Geiranger with bus.	1500	50%
3	Redirection to nearby ports (a)	Cruise ships arrive at Olden (node 9 in Figure 4) or Nordfjordeid (node 7 in Figure 4) and passengers are further transported to/from Geiranger with bus.	3500	20%
4	Redirection of nearby ports (b)	Cruise ships arrive at Ålesund (node 11 in Figure 4), and passengers are further transported to/from Geiranger with bus.	3500	20%

The first scenario includes a "Blue corridor" where cruise ships get a dispensation from the parliament regulation and may sail without emissions restrictions to Hellesylt port, located within the world heritage site. In the second scenario, a new cruise port is established at Stranda, located just outside the world heritage site. Due to the harbor layout and capacity, it is assumed that this scenario includes cruise ships with smaller passenger capacities than the other scenarios. In the last two scenarios, situations where no dispensation or technology compliance measures are implemented are analyzed. Scenarios three and four explore ships redirected to nearby ports at Olden/Nordfjordeid and Ålesund respectively.

Data sources

Total number of sea and land tourist to/from Geiranger

For the reference scenario, the number of tourists and vehicles arriving at Geiranger in different seasons in 2018 was estimated based on an appraisal from Yttredal et al. (2019). In this study, publicly available data sources were used to estimate the number of tourists and vehicles arriving at Geiranger center. The number of tourists arriving by sea was estimated based on data sources including The Ferry Database, information from the Fjords, databases from Norwegian Public Road Administration (NPRA), information from Stranda Port Services, and information from Hurtigruten AS. The number of vehicles arriving in the area was estimated based on data from The Ferry Database and databases from NPRA. The total number of tourists arriving without a vehicle and the total number of cars and caravans are considered in this study.

In-situ questionnaire

An in-situ questionnaire was conducted on a total of 20 days in July and August in 2018 at seven locations around Geiranger: at two ferry quays (Eidsdal and Linge), onboard the ferry Hellestylt-Geiranger, at Geiranger center, and at three viewpoints close to Geiranger (Korsmyra, Flydalsjuvet, Dalsnibba). These locations covered all the accesses to Geiranger, north, west, and south.

The questionnaire was divided into three main parts: (1) socioeconomic information of the respondents; (2) description of the trip to or from Geiranger, including the origin or destination, transport mode, route choice, and route motivation; and (3) description of mobility within Geiranger village, i.e., transport mode, length of stay and attraction points visited. To avoid questionnaires with a duration larger than 10 minutes, tourists were divided into three groups depending on they were traveling toward Geiranger, in Geiranger, or on their way out of Geiranger. The former group answered questions related to their trip to Geiranger; those in Geiranger completing also the questions related to the mobility within the area; and the latter group answered questions related to their trip from Geiranger and to the mobility within the area. (The survey was approved by the Norwegian center for research data (NSD) in relation to personal information and privacy policies, under the SUSTRANS project. For more information regarding the survey, please see Babri and Díez-Gutiérrez (2019)).

The survey was designed as a self-completed questionnaire in several languages, coded in QuenchTec (QuenchTec, 2018), presented a logic structure as not all questions were answered by all respondents. The tourists could complete the survey on-site through a PDA. Two or three interviewers approached tourists at the locations, aiming to randomly cover the diverse demographic characteristics of them. This approach can be categorized as probability sampling technique since the respondents are randomly chosen in Geiranger center and other mostly visited locations in the area (Yang et al., 2006). There was a possibility to scan a QR code to complete the survey at other more convenient time, however, the participation with this code was less than 1%. In total, 915 tourists completed the questionnaire correctly.

Road network

Data on road characteristics, including travel distance (km), speed limit (km/h), road width (m), and travel cost (€), were obtained from the Norwegian national road database (NVDB, 2021). However, in modeling tourist traffic, characteristics related to road attractions are also important (Díez-Gutiérrez & Babri, 2020). Thus, the number of facilities (accommodations and restaurants), outdoor activities, and sightseeing places within a buffer of 2 km along the roads were obtained from Visit Norway (2021b). Natural features of the road surroundings, such as water bodies and forests, were obtained from the Norwegian Mapping and Cadastre Authority (Katverket, 2019). To include them into the model, it was considered a 500-meter buffer on each side of a road and estimated the percentage of the road where these natural features could potentially be seen.

Bus operators' routes

Data on the routes of short bus tours and shuttle buses were mainly obtained from websites related to tour operators (Geiranger Fjords Service, 2021; Norway Travel Guide, 2021; Visit Norway, 2021c), where tourists could find all the available bus routes in the area, schedules, and prices. These data were compared to data from local tour agencies.

Traffic counts

Data from traffic counting stations of NRPA (Trafikkdata, 2021) were obtained for the counting stations I.1 and E.3 in Figure 1. These data include the number of vehicles in both directions to/from Geiranger. The registered vehicles are divided into five categories depending on their length.

Ferry tickets

Data on ticket sales from the ferry database (Ferjedatabanken, 2021) and information from The Fjords (The Fjords, 2021) were acquired for the ferry connection (counting stations E.1 and E.2 in Figure 1). These databases register the number of vehicles in each direction without specifying the types of vehicles. It was assumed that the distribution of different types of vehicles on these road segments was equivalent to the distribution from traffic counting stations from other road segments in the area.

Video recordings

Data from video-based registration of traffic (Dahl & Meland, 2018) were also used. These cameras were installed at strategic points along the local roads in Geiranger. Traffic counting stations I.2 and I.3 in Figure 1 represents video-based counting stations. The registered traffic was divided into five categories: pedestrian, bike, heavy vehicles, caravans, and light vehicles. Of these, the last three categories were relevant to the model developed in this study.

Expert judgment

A series of expert interviews and workshops were held to develop transport scenarios for 2026. Initially, multi-stakeholder workshops with representatives from local authorities (Stranda municipality and port authorities, and the local world heritage foundation), tour operators, and from the local tourist industry (such as hotels or shops) were held to specify a set of relevant and possible scenarios for 2026 (ÅKP, 2020). This resulted in four primary scenarios within which to explore alternative transport system solutions. Further specification was acquired through expert judgment made by the local port authorities, cruise lines, cruise handling agencies, bus operators, and local tour agencies to provide estimates of potential cruise traffic volumes within each scenario as well as cruise-generated land traffic (Aspen et al., 2020). The final scenarios and transport system solutions were presented and validated in another multi-stakeholder workshop to ensure their relevancy. The number of tourists for 2026 was also estimated under these workshops.

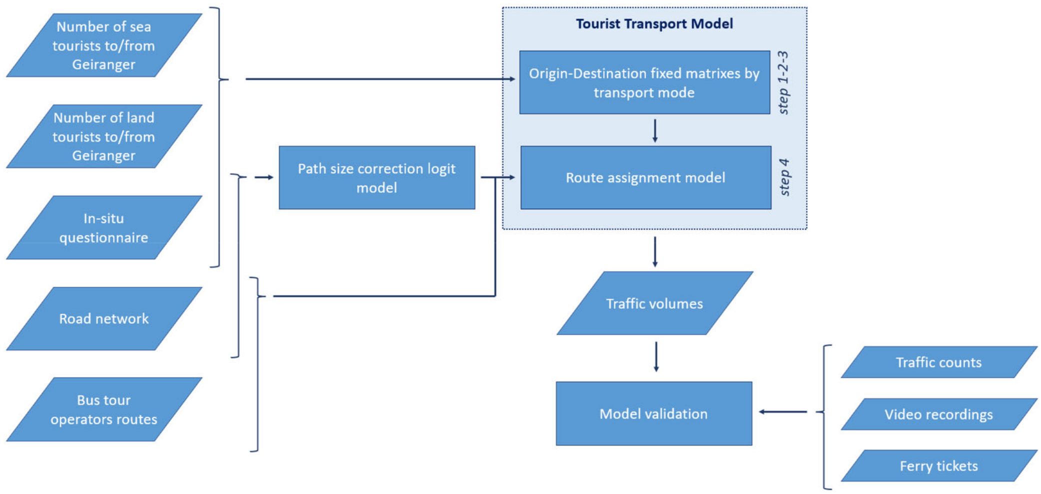

Figure 2. Structure of the tourist traffic application module.

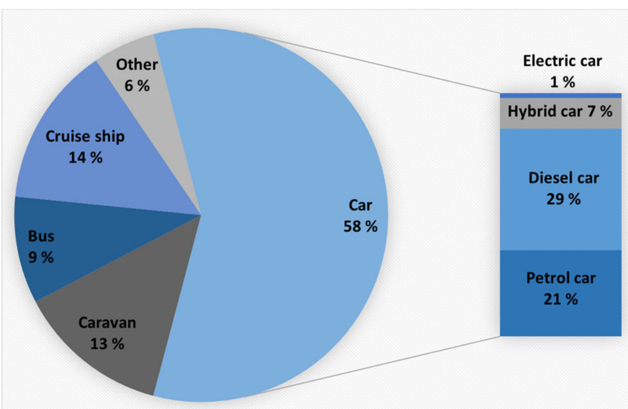

Figure 3. Tourist preferences for transport mode (percentage over all responses N = 855).

Transport model

The four-step model is a well-established method in transport modeling; however, it is not fully exploited in the context of tourism transport. This paper aims to contribute to the transport modeling literature by applying a four-step transport model into a research area which is not fully studied mainly due to lack of data. Throughout this section, we briefly mention the model and explain how it is set up to simulate the tourist transport in the studied area.

A conventional four-step transport model consists of trip generation, trip distribution, mode choice, and route assignment (Ortúzar & Willumsen, 2011). Our transport model, displayed in Figure 2, further builds on these steps.

In traditional transport models, the first two steps are estimated based on descriptive statistical models, while the third step is based on behavioral models (Le Pira et al., 2021). In our research, the first three steps were jointly estimated based on the questionnaire data, which depicts the origin-destination (OD) distribution by transport mode and the total number of land and sea tourists visiting Geiranger. For sea tourists, an estimate for tourists disembarking and further traveling with sightseeing buses was acquired via expert judgment, as described in the previous section.

The conventional route assignment step is based on the user equilibrium, i.e., the cost of each route varies until no one can reduce their cost by choosing another route (Wardrop, 1952). Nevertheless, tourists present different travel behavior than other users (Page, 2009), and thus, route selection might respond to other underlying factors. In this research, the route assignment model was based on a PSCL model. Moreover, the road network features, and the bus tour operator routes were also input in this step. The output of the module was validated against road traffic counts, video recordings, and ferry ticket sales.

Origin-destination distribution

Data extracted from the questionnaire allowed to define an origin-destination (OD) distribution of tourists using different transport modes (car, caravan, and bus). Coupling these data with the total number of tourists in the area (Yttredal et al., 2019), fixed origin-destination matrixes per transport mode were found. It should be noted that only oridin-destination pairs with origin or destination in Geiranger were considered, i.e., trips to or from Geiranger, thus, excluding intra-destination movements. From the questionnaire data, Ålesund, a city located 110 km toward the northwest of Geiranger center, was the most popular origin or destination point for land-based tourists. In addition to Ålesund, other potential points, shown in Figure 1, were named for land-based tourists: Oslo, Bergen, Trondheim, Molde, Grotli, Åndalsnes, Voss, Sogndal, Førde, Stryn, Runde, Valldal, Eidsdal, and Stranda.

Figure 3 illustrates findings on tourists' mode choice for traveling to/from Geiranger. Around 95% of the tourists arrived at Geiranger by car, caravan, bus, or cruise ship. Therefore, these modes were included in the transport model.

It was observed that cruise passengers mainly arrived at Geiranger or Hellesylt, a village located west of Geiranger, an 18-kilometer aerial distance. Those disembarking in Hellesylt were further transported to Geiranger by bus. Through the questionnaire data and interviews with stakeholders and authorities, four additional ports in the area were identified, including Olden, Nordfjordeid, Ålesund,

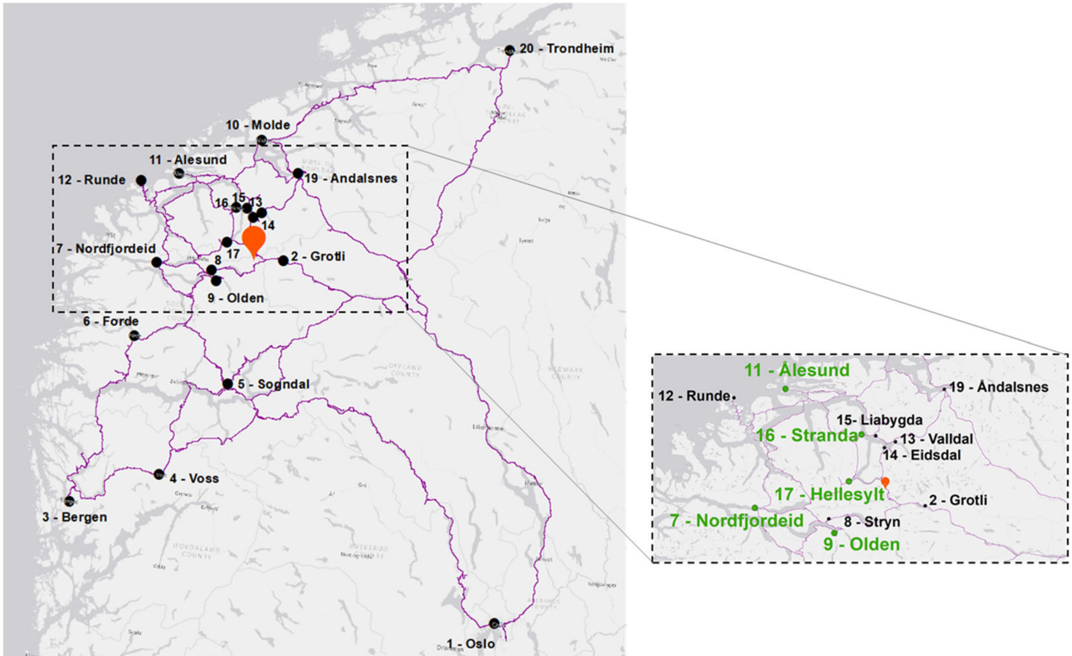

Figure 4. Base network for the transport model – ports marked with green.

and Stranda, which were either already used or could be used disembark cruise tourists to Geiranger. Figure 4 illustrates all the 20 points (including Geiranger) nodes that are the basis for the model's network.

Three different types of buses were incorporated in the model: 1) local bus tours within the Geiranger center and surrounding areas for all tourists not coming with their private vehicle, 2) shuttle buses for cruise passengers arriving at other ports (close to Geiranger, marked green in Figure 4) who needed to be transported to Geiranger by bus and 3) scheduled or tourist buses which took tourists to Geiranger from other destinations.

The cruise-generated bus traffic, either local bus tours or shuttle buses, was assumed to depend on the number of cruise passengers arriving at the area and the percentage of tourists embarking on buses. It was assumed that the capacity of each bus was 45 tourists per bus.

Route assignment

The choice of the route to/from Geiranger for tourists arriving by car or caravan was based on a PSCL model estimated in Díez-Gutiérrez and Babri (2020). The explanatory variables for choosing a route were related to the route features: travel time, road width, road scenery (water bodies and forests), sightseeing places, outdoor activities, and facilities. The perception of these road features varied according to the socio-economic and trip characteristics of the tourists. Tourists living in Norway were less attracted to routes with the possibility to participate in outdoor activities, while sightseeing places were only relevant for first-time tourists. Tourists traveling by caravan were less attracted to the road with more facilities, and local roads were preferred for tourists whose route motivation was sightseeing. These findings and the estimated parameters were incorporated into the route assignment step in the transport model.

Routes for shuttle buses and local bus tours were modeled based on the routes already used by bus operators. For scheduled or tourist buses from further destinations, the fastest route assignment method was used.

Model validation

The transport model was coded in Cube Voyager (see, Bentley (2020)). To validate the model, a reference scenario was defined, and the modeled traffic was compared to the registered traffic from counting stations, ferry ticket sales, and video recordings. The reference year for model validation is set to 2018, since the in-situ questionnaire was conducted in 2018 and number of tourists arriving in Geiranger is estimated for this year. The registered data is available over the years, thus for validation purposes, data from 2018 is extracted.

The total number of vehicles arriving at Geiranger during the whole year was set around 217,000 vehicles. Of these, 85% were estimated to be light vehicles such as cars (length lower than 5 meters), 6% were medium-size vehicles such as caravans (length between 5 and 7,5 meters), and the rest were heavy vehicles such as buses (length longer than 7,5 meters).

The monthly distribution of the tourists throughout the year is an essential factor to consider as it influences potential bottlenecks or congestion in certain areas. For modeling purposes, four time periods were estimated: 25% of the cruise tourists were assumed to visit the site in July; 45% in June and August; 25% in May and September; and 5% in April, November, and October. There was a negligible number of tourists arriving between November and April.

In the reference scenario, which we used data from 2018, around 250,000 passengers arrived at Geiranger through sea access. Previous studies showed that more than half of cruise passengers take pre-booked bus tours to explore the

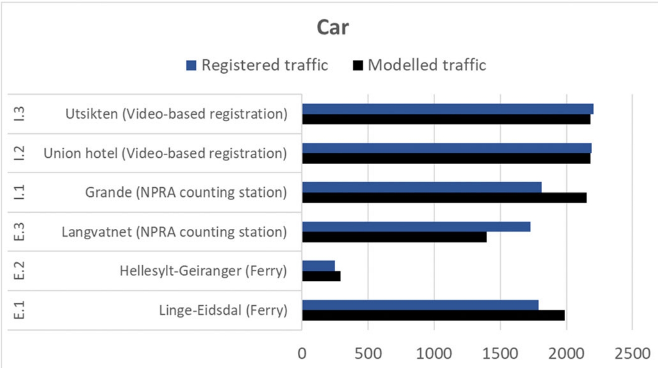

Figure 5. Modeled car traffic versus registered car traffic in counting stations (ASDT in 2018).

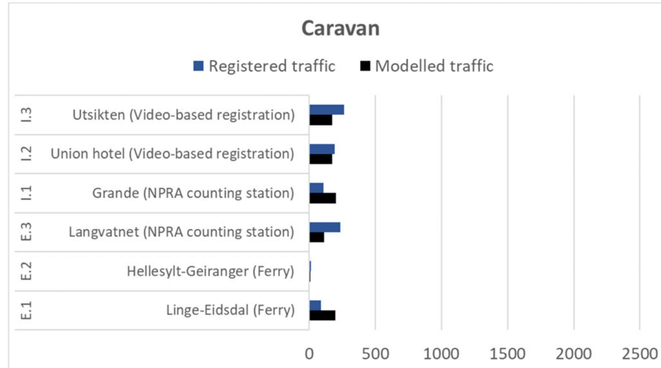

Figure 6. Modeled caravan traffic versus registered caravan traffic in counting stations (ASDT in 2018).

surrounding area (Svendsen et al., 2014), while the rest might book on site. The exact number of tourists taking bus tours was thus unclear. Through interviews with experts and authorities, there was estimated that 90% of those disembarking at Geiranger took local bus tours to explore the surrounding.

Figures 5–7 illustrate modeled traffic versus registered traffic from counting station for an average summer daily traffic (ASDT) in 2018 for cars, caravans, and buses, respectively. As observed in Figures 5 and 6, the model adequately assigned the traffic volume in the area, given that the total number of cars and caravans were provided to the model as input. The distribution deviation was around 2% of the total traffic volume for cars while it was 3% for caravans. For the external counting stations, the model slightly prioritized the ferry accesses over road access. The overestimation of traffic for both cars and caravans in one internal counting station I.1 was also associated to overestimation of arriving/departing traffic to Geiranger through north access with ferry connection Linge-Eidsdal.

According to Figure 7, the model reasonably estimated the bus traffic volumes in the area, given that the number of cruise passengers and bus tourists were provided to the model and the bus routes were coded into the model. The distribution deviation was less than 10%, some deviations in traffic volume distribution especially in external counting stations might be associated to the limited capacity of some bus trips offered to the cruise tourists; an information which was not accessible, and, therefore, assigned the cruise passengers to the available routes evenly.

The validated model is further used to analyze the scenarios, with the planning horizon in 2026. We argue that the route choice, mode choice and intra-destination choice would not differ significantly from the reference year, i.e., 2018. And therefore, the distribution of these choices is assumed unchanged. The number of tourists arriving, however, are estimated by experts for the planning year 2026.

Emission and congestion calculation

Based on the modeled traffic volume, the environmental footprint of land transport, CO_2, NO_X, and PM, was calculated within the studied area and in the UNESCO-protected area (see Figure 1 for definition of studied area).

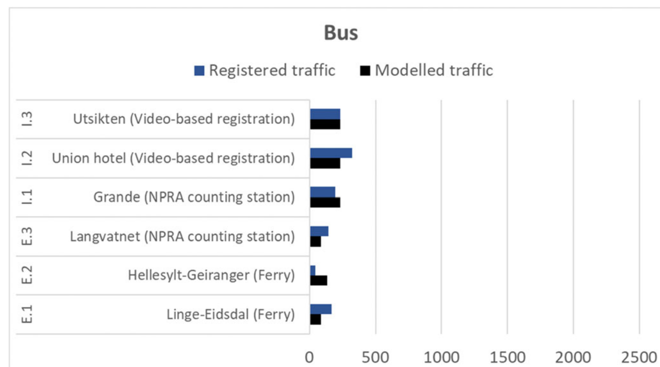

Figure 7. Modeled bus traffic versus registered bus traffic in counting stations (ASDT in 2018).

In addition to the traffic volume on roads, the type of vehicles plays a vital role in the environmental footprint of road traffic. Survey data revealed that half of the cars arriving at Geiranger were diesel cars, while 36% were gasoline, 13% were hybrid, and the rest were electric cars (Figure 3). This distribution of vehicle type was assumed for reference and future scenarios. All caravans and buses were assumed to run on diesel. This assumption is based on the studies evaluating alternative technologies for long-distance buses in rural areas within the planning horizon 2026 (Hagman et al., 2017). Buses with Euro V and Euro VI standards have similar emission parameters for CO_2 and NO_X while having different PM parameters (Hagman et al., 2017). In all analyzed scenarios, all buses were assumed to be Euro V standard for calculating PM emissions.

In our study, we used an energy model which accounts for both road and vehicle characteristics and traffic volumes (Hjelkrem et al., 2017). However, this method only was developed for calculating CO2 and NOX. For calculating PM, we followed an approach of using an emission parameter for the driven kilometers (Hagman et al., 2017).

In addition to the emission estimation, potential congestion was estimated based on traffic volume and characteristics of the roads. Hjelkrem et al. (2017) calibrated volume-delay functions within the Norwegian context and different types of roads, based on data from more than 280 counting stations all over Norway; these functions were incorporated into the Norwegian Regional Transport Model (RTM). In this research, the calibrated volume-delay functions in RTM

Figure 8. Congestion level for a peak hour in July.

were used to calculate the increased travel time as a proxy for congestion on roads (Hjelkrem et al., 2017). For ferry connections, it was assumed that when the traffic exceeded the capacity for the ferry, the travel time was increased by the ferry headway. Under each scenario, the increased travel time was calculated for a peak hour in July. Based on historical data from the counting stations, it was observed that traffic volume in the peak hour accounted for 10% of the daily traffic.

Results

The focus of this section is the analysis of the cruise-generated bus transport under each scenario, as the demand for other transport modes remains unaffected.

Figure 8 shows the congestion level on the roads or ferry connections in the studied area for a peak hour in July for each scenario; green links show free flow, i.e., a situation where traffic on the road can follow the speed limit; red links indicate more than 5% speed reduction on the link due to traffic volume, while yellow links indicate speed reduction in the range of 0 to 5% due to traffic volume. In addition, Table 2 depicts "lost hours" in congestion for all tourists in the area in a peak hour in July, i.e., how many hours all tourists in total would lose in congestion within one hour.

Our results show that for scenario 1, cruise ships that arrive at Hellesylt port will worsen the current congestion situation as tourist buses increased traffic volumes in the detour road from Hellesylt to Geiranger, triggering some congested road segments. The "lost hours" in scenario 1 is more than doubled compared to the reference scenario. For scenario 2, where cruise ships arrive at a new port in Stranda, the ferry connection between Hellesylt and Geiranger becomes overloaded. This causes a delay for the ferry, which has a relatively high headway (90 minutes). Consequently, the "lost hours" for the tourists are significantly higher in Scenario 2 compared to other scenarios.

In scenario 3 and 4, where cruise ships are called to nearby ports in Olden/Nordfjordeid and Ålesund respectively, fewer cruise passengers were assumed to travel to Geiranger by bus, which results in less congestion than the first two scenarios. This congestion takes place on road segments in or around Geiranger. As buses from Ålesund (scenario 4) use the north access road, the ferry connection between Linge and Eidsdal becomes critically congested in a peak hour in July. It is worth mentioning that the frequency

Table 2. Time in congestion (lost hours in congestion for all tourists in the area in a peak hour in July).

	Reference	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Lost time in congestion (hours)	4	9	58	1	7

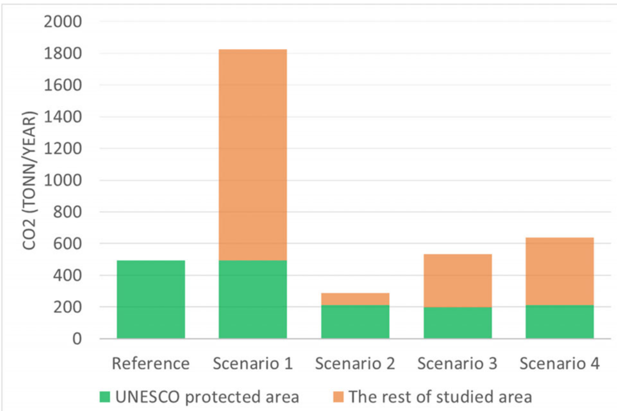

Figure 9. Total CO2 emission from cruise-generated bus transport in the studied area.

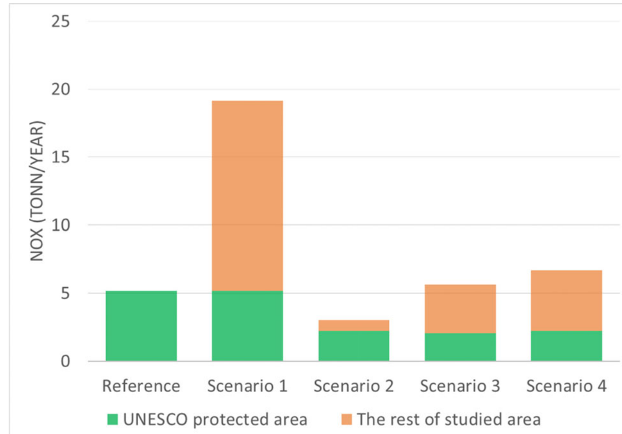

Figure 10. Total NOx emission from cruise-generated bus transport in the studied area.

of the ferry connection is assumed to remain unchanged throughout all scenarios to keep the congestion situation comparable through scenarios. This would lead to unchanged emission level from ferries, thus the ferry emission from ferries excluded in the emission calculations.

Figures 9–11 presents annual CO_2, NO_X, and PM emissions respectively from the cruise-generated bus transport within the studied area. The figures differentiate between those emitted within the UNESCO protected area, and outside this area.

CO_2 and NO_X emissions follow a similar pattern across scenarios as both were estimated based on the same factors. PM emissions were estimated without considering the geometry of the road, which disregarded the mountainous terrain of the UNESCO-protected area. This led to a lower percentage of PM emissions in the protected area in relation to the studied area. This difference was especially relevant in scenario 2, as 75% of the CO_2 and NO_X emissions were concentrated in the protected area, but only 60% of the PM emissions.

In the reference scenario, all cruise tourists arrived at Geiranger. Emission estimates in these scenarios are therefore only in the UNESCO-protected area. In scenario 1, there is a significant increase in emissions compared to the reference scenario as a large portion (50 percent) of cruise tourists were assumed to go to Geiranger by bus. The same fraction of tourists was assumed to travel to Geiranger by bus in scenario 2, but since the Stranda port only may accommodate smaller ships, fewer tourists entered the area, thereby generating far less emissions than those estimated in scenario 1. In scenarios 3 and 4, emissions estimates are close. Emissions are slightly lower in scenario 3 due to a shorter road distance, a smooth road geometry, and less congested road segments. Moreover, it is observed that less emissions are generated within the protected area in scenarios 3 and 4, mainly because fewer tourists would take the bus from further ports to Geiranger. However, due to longer travel distances, these scenarios have higher total emissions within the studied area than in the reference scenario.

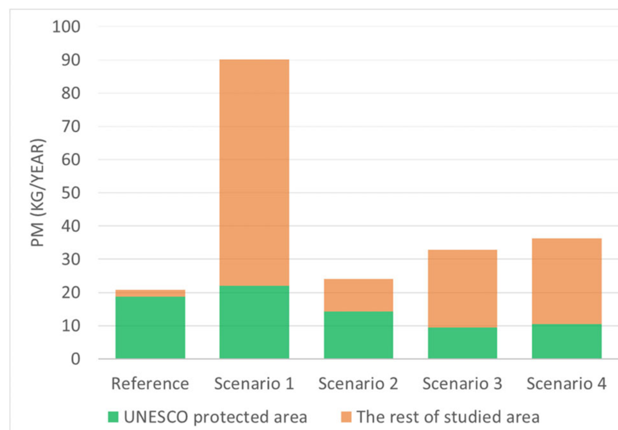

Figure 11. Total PM emission from cruise-generated bus transport in the studied area.

Table 3 shows the percentage of emissions that represents the cruise-generated tourist bus transport over all vehicle types within both the studied and the UNESCO protected areas for a year.

In general, emissions from cruise-generated buses are relatively high compared to other vehicle types on the roads. This traffic represents more than 60% of the total NO_X emissions in scenario 1. The share of the NO_X emissions is larger than for the CO_2 emissions, although both presents similar relationships across scenarios. The emissions share in scenario 1 increases for the studied area, although it remains unchanged in the protected area when compared to the reference scenario. Conversely, in scenario 3 and 4 the emission percentages are reduced from the UNESCO area but increased in the studied area, compared to the reference scenario. Scenario 2 shows a reduction of the cruise-generated bus traffic both in the UNESCO-protected area, as well as in the entire study area. This is not surprising as this

Table 3. Percentage of emissions from cruise-generated bus traffic over the total traffic volume.

	Reference	Scenario 1	Scenario 2	Scenario 3	Scenario 4
CO_2					
Studied area	19 %	47 %	12 %	21 %	24 %
UNESCO prot. area	44 %	44 %	25 %	24 %	25 %
NO_X					
Studied area	32 %	63 %	21 %	34 %	37 %
UNESCO prot. area	60 %	60 %	41 %	38 %	41 %

scenario considers smaller cruise vessel and thereby fewer cruise tourists making local trips.

Discussion

Results from our model shows that policies aiming to reduce air emissions in one part of the network may have adverse effects on another part of the network. In the studied case, the net zero emission policy for sea traffic in the Geiranger area might worsen the road traffic, leading to an undesired emission increase in the overall picture. As shown in scenario 1, it triggered more than triple the overall GHG emissions from the reference scenario. In scenarios 2, 3, and 4 there was a relocation of the ports and a reduction in the number of cruise passengers visiting Geiranger. The overall GHG emissions were only reduced by scenario 2 compared to the reference scenario. Nevertheless, it presented similar PM emissions and slightly lower CO_2 and NO_X emissions than scenarios 3 and 4 in the protected area. In addition to the GHG emissions by the cruise-generated bus transport, the location of the cruise port destinations also affects the spatial distribution of the congestion road segments, and thus the emissions from other vehicles which spend more time driving on these congested roads. This research proves that an integrated framework including all transport modes should be followed, as targeting only sea transport might not achieve the desired sustainable outcomes.

Reducing emission levels and road congestion may be done following multiple measures. As our results show, there is already a high traffic load on road segments in the area due to regular tourist traffic. Crowding and congestion were already negatively perceived by local stakeholders in the context of sustainable development of the area (Yttredal & Homlong, 2020). Options such as zero-emission vessel taking tourists to Geiranger from nearby ports are promising provided that it is technologically and financially feasible. Norway is leading the transition toward cleaner maritime transport, with 61 electric ferries in operation this year (Saether & Moe, 2021). This would reduce both emissions and traffic loads on road segments in the area. Other options are electric buses, which have the potential to mitigate GHG under clean energy sources (Song et al., 2018), although not in the planning horizon for this study (Hagman et al., 2017). In Norway almost 75% of the energy source comes from renewable energy sources, mainly flexible hydropower (Norwegian Government, 2021), which makes electric buses a green alternative in a well-to-wheel perspective. Nonetheless, the traffic load will remain unchanged, and thus, congestion will not be reduced. Zero-emission cars does not seem to be promising options as this would increase the traffic load on road segments in the area beyond what cruise-generated bus traffic already would, moreover, it could overload sightseeing places with limited parking capacity. Other personal transportation modes for rental in tourist destinations have gain market lately, ultra-lightweight vehicles are an attractive alternative for tourists, preferred against electric bicycles or motorbikes, as these are perceived as safer (Nakamura & Abe, 2016). Electric bicycles, unlike the other transport modes, requires investing in cycle infrastructure to encourage their use (Maas et al., 2020).

While our model is a first attempt at coupling road and sea traffic dynamics, it may be further improved to offer increased accuracy. The collected data were based on an in-situ questionnaire with a high response rate. The detailed level of the questions allowed to partially reconstruct the tourists' movements. More complete and dynamic data could improve the accuracy of the developed model, especially including intra-destination tourists' movements. An example could be GPS tracking of tourists, which provides more accurate data, and information of the visiting points and time spent at the sightseeing locations along the roads. Further knowledge of time spent at these locations could be used to limit the visiting time periods which could affect the road congestion, offering a better distribution of traffic over the course of a day. Moreover, studies suggest that spatial intra-destination behavior of tourists affects their expenditure which is an important factor in tourism management (Domènech et al., 2020). Despite the importance of intra-destination movements, these have not been studied extensively in the literature mainly due to lack of accurate and reliable data and lack of adequate theoretical framework (McKercher & Zoltan, 2014).

Our model follows a four-step traditional transport model, where inputs are already classified origin-destination trips by transport mode. The model was contrasted to video recordings and traffic counts showing a good performance, thus for low density transport networks there is no need to contemplate more complex models. Nevertheless, improvements for the transport demand estimation could be applied. To simulate policies related to changes in land use, such as accommodation or tourist activities, assumptions and manual adjustments would be needed. Further development of the model could be to add a mode choice based on some revealed and preference data, which will allow observing the responses to scenarios replicating policies where tourists can choose between different transport modes. In addition, movement patterns of tourists might be influenced by personal characteristics (Plog, 2002) or cultural background (Dejbakhsh et al., 2011), thus including tourist clusters to simulate transport demand to different destinations become significant as different underlying explanatory factors rely in the decision process.

Emissions from transport activities are often calculated based on average parameters, overlooking the effects of topography and local details. This approach offers an adequate estimation of emission in large areas, but it might not be appropriate for calculating emission within small areas with topography similar to that in Geiranger. Therefore, this research emphasizes the need for a more specific approach to measure GHG emissions, as vehicle type and topography elements play a significant role in emission levels. Moreover, a useful development could be to include the GHG emissions in one of the sustainable indices to compare scenarios at different spatial and temporal scales.

We believe that the approach presented in this paper can be retrieved and applied in destinations with similar characteristics, i.e., rural touristic areas where there are several tightly interconnected transport modes. As presented in this study, the connection between the modes should not be overlooked though it does not need to be complicated from the modeling technique perspective. As it is known in the literature, availability of data is among the major problems in tourism transport modeling. The data collection must therefore be tailored to the destination under study.

This study is limited to analyze emissions and congestion effects of transport policies to highlight the importance of a holistic systematic approach in destinations with several interconnected transport modes. Another important aspect, though outside of the scope of this paper, is the consequences of implementing the net zero emission policy for tourism transport on local economy and employment. Emission reduction policies might limit the number of tourists arriving at the area, as the scenarios in this study do. This might negatively affect local economy. Therefore, the decision-making process for selecting optimal policies should maintain a holistic perspective, including socio, economic aspects and investment and operational cost of scenarios in addition to and environmental aspects. The presented method, although addressing the integration of sea and land transport, do not include social or economic variables, thus it cannot stand alone.

Summary and conclusion

Tourism transport may lead to significant air emissions and congestion problems on road networks. This is particularly troublesome for nature-based tourism destinations, as they often are in rural areas with low transportation capacities and vulnerable nature. We develop a transport model to estimate traffic volumes, spatial and temporal congestion distribution, and GHG emissions along road segments in a transport network based on transportation activity at land and sea. The model is applied to a case study of the Geiranger fjord UNESCO world heritage site in Norway.

Relocating the cruise disembarking ports outside the UNESCO protected area does not reduce the GHG emissions in this area as the cruise-generated tourist buses may contribute more than 60% of the total road emissions for certain scenarios. Moreover, these buses generate congestion at some road segments triggering more emissions from other vehicles. This research shows that changes in sea transportation affect land transportation. Therefore, an integrated approach should be followed. The use of a simple transport model provides a valuable understanding of the consequences of different policies, serving as a complementary tool in the assessment of sustainable tourism policies.

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