ESTABLISHING A BASIS FOR DECISION SUPPORT MODELLING OF FUTURE ZERO EMISSIONS SEA BASED TOURISM MOBILITY IN THE GEIRANGER FJORD AREA

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ABSTRACT

Destinations for cruise tourism have to manage both opportunities and challenges of hosting cruise ships. Governing bodies in Norway are proposing new environmental regulations to abate environmental impacts, but some stakeholders worry that stringent regulations will cause less value generation for local business. The purpose of this paper is to establish a basis for decision support modelling on future zero emission sea-based tourism mobility for the Geiranger fjord area. The tourism mobility system is mapped through a systems engineering lens. The analysis systematizes the tourism mobility system, prior studies on air pollution and emissions, existing- and upcoming regulations. The study concludes by proposing an objectives hierarchy and measure of effectiveness for use in future works.

INTRODUCTION

The Geiranger Fjord is one of the hallmarks of Norwegian tourist attractions known for its pristine nature. Recently the area has been under much debate due to rising air pollution from traffic and seaborne activity. The Norwegian Maritime Authority has been assigned by the Norwegian Environmental Protection Agency to consider new environmental regulations regarding emissions to air for large ships operating on the Norwegian World Heritage Fjords. This is anticipated to reduce emissions from ships, but business actors in Geiranger fear that this will reduce the number of port calls in Geiranger and divert tourists to buses (increased road transport) from other cruise ports nearby (nrk.no). This is one example of many conflicting stakeholder interest needed to be balanced when making decisions on which new environmental policies that should be implemented. Therefore, the current study aims to formalize the system of tourism mobility and establish an objectives hierarchy for the case of reducing emissions to air from tourism-based mobility in the Geiranger fjord based on systems engineering methodology to further be used in future studies on decision support modelling.

GEIRANGER

Geiranger is a remotely located and scarcely populated village on the west coast of Norway with only 230 permanent residents. The village is situated in a landscape recognized from its steep fjords and rural landscape, listed as a UNESCO World Heritage site.

Figure 1: Geiranger, Photo © Stranda Port Authority

Geiranger is one of Norways' most visited cruise ports, receiving 346.327 passengers in 2018 (Yttredal et al., 2019). The majority of the remaining tourists arrive by private cars or chartered busses. This mobility brings many challenges in Geiranger where the infrastructure is beginning to reach its capacity due to the increasing influx of tourists (Tallaksen and Holm, 2007). This is in line with the findings of Dickinson and Robbins (2008) examining the traffic problems related to tourism at rural destinations.

A study on mobility in Geiranger was made by Shlopak et al. (2014). The second part of this study, Svendsen et al. (2014), assessed the emissions from sea- and land-based transport in Geiranger. The topic was further studied by Weggeberg et al. (2017) conserning emissions from ships in Geiranger and Nærøyfjord on

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behalf of the Norwegian Maritime Authority (NMA). The Norwegian Ministry of Climate and Environment has initiated NMA to consider options for imposing regulations reducing the environmental impacts from shipping in Nærøyfjord, Aurlandsfjord, Geirangerfjord, Synnulvsfjord and the inner part of Tafjord (regjeringen.no). The current study seeks to use a systems engineering lens to systematize previous studies together with existing and upcoming regulations to establish a basis for decision support modelling on future zero emission sea-based tourism mobility for the Geiranger fjord area.

MOBILITY IN THE GEIRANGER AREA

The tourism mobility system in the Geiranger area entails the characteristics of a system as defined by NASA (2007) being "*...a construct or collection of different elements that together produce results not obtainable by the elements alone.*" The two elements at the top-level in the taxonomy describing the transport system in Geiranger are road transport and seaborne transport. The next level in the taxonomy divides between the main categories of transport within the elements road and seaborne traffic. These are light- and heavy vehicles for road transport and ferries, cruise ships, guding boats, tender boats and RIB boats for seaborne transport.

Geiranger cruise port comprises a cruise terminal, seawalk and up to four anchor positions depending on the size of the ships. There are on average 1-2 cruise ships anchored up in Geiranger in the tourist season. The number of curise passengers in Geiranger is limited to 6000 PAX. Most of the passengers landing from the Cruise ships enter by the cruise ships' own tender boats. There is an own terminal for the tender boats at Geiranger port. The tender boats have a capacity around 150 PAX and are driven by small marine diesel engines, typically around 200 kW. Cruise ships normally use 2-4 tender boats on each port call (Svendsen et al., 2014). It is possible to travel to Geiranger by ferry from the village of Hellesylt with daily departures in the period May through October. In the peak season between June and August, the ferry takes eight roundtrips. The ferry service is run by the vessels "Bolsøy" and "Veøy", built 1971/74, with capacity of 36 cars and 345 passengers (Svendsen et al., 2014). Geiranger Fjordservice operate sightseeing boats on the Geiranger Fjord. In the peak season between June and August there are 11 daily roundtrips. Local tour operators also arrange daily excursions on high-speed RIB boats on the Geiranger Fjord. The vessels carry around 15 passengers per trip and are powered by marine diesel engines around 250 kW. For the 2014 season, about 700 trips were arranged (Svendsen et al., 2014).

Although much of the debate on environmental impacts from tourism in Geiranger focuses on emissions from cruise ships, the bulk of tourists coming to Geiranger are arriving with cars and busses. There are three points of entry in to Geiranger (see figure 2 for reference). From the north through Ørnesvingen from Eidsdal, from the south through Flydalsjuvet from either Grotli or Stryn. The third is by ferry directly to Geiranger. Both the northern and southern route in and out of Geiranger are serpentine mountain roads, characteristic for the area and an experience by themselves, but a challenge with regards to traffic. Calculations of traffic capacity shows that the road network outside the center of Geiranger, can withstand 1100 vehicles per hour, which is well above the actual daily traffic level in the peak of the season (Svendsen et al., 2014). Problems arise when multiple vehicles and especially multiple busses are trying to navigate through the narrow streets of Geiranger center or the tightest bends on the serpentine mountain roads. Queues are also expected to occur as drivers of private cars seek parking in Geiranger.

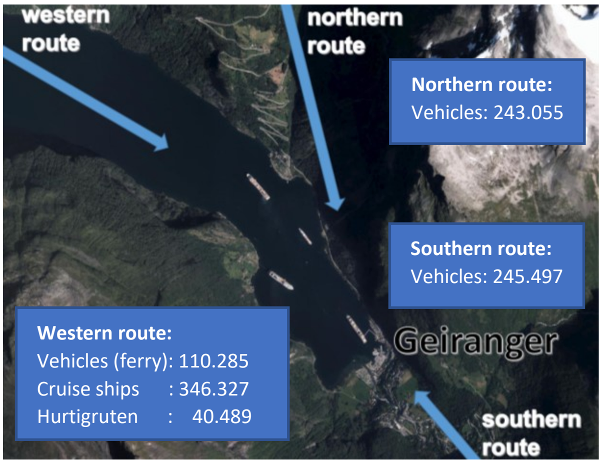

Figure 2: Entry points to Geiranger with respecive number of visitors in 2018 (Yttredal, et al., 2019) Photo © GuleSider

In 2013, the annual mean value of vehicles through Geiranger center per day was measured to be 562 vehicles per day. The corresponding value for the summer months (June, July, August) (SDT) was 1375 and for July alone (JDT) it was 1779 vehicles per day (Svendsen et al., 2014). The Norwegian Public Roads Administration divide between heavy and light vehicles saying that all vehicles above 5,6 meters are considered as heavy vehicles and correspondingly the opposite for light vehicles. In prior studies by Svendsen et al. (2014) it was estimated that heavy vehicles represent between 14% (Svendsen et al., 2014) and 8% (Diez-Gutierrez and Babri, 2020) of the road-traffic in peak season. In addition to higher traffic in general, the activity by heavy vehicles like buses that are more emissions intensive is higher in the peak of the season. One concern expressed by some stakeholders in Geiranger is that they worry that impending strict regulations for emissions to ships operating on the Geiranger Fjord would redirect vessels to other ports nearby and that the tourists would be transported in to Geiranger with buses instead.

AIR POLLUTION IN GEIRANGER

Prior studies show that emissions to air in Geiranger mainly come from combustion of fossil fuels in ships and vehicles as well as abrasion and wear of roads due to traffic. Emissions from combustion of solid biofuels for heating of residential buildings is outside the scope of this study. It is also not relevant for the tourist season as it is in the middle of summer where heating demand for housing is at a minimum.

Focus is put on (sulfur dioxide) SO_2 , nitrous oxide NO_x and particulate matter (PM). An important constituency of the $PM_{2.5}$ emissions fraction is black carbon. Black carbon originates from incomplete combustion of hydrocarbons. Black carbon serves as a carrier for heavy metals, inorganic salts and organics such as PAHs that are known for adverse health effects. Due to this, the exhaust from diesel engines is classified as carcinogenic to humans. Exposure to NO_x may cause impaired lung function, increased susceptibility to respiratory infections and development or worsening of asthma and bronchitis (WHO, 2016). According to the study "Air Quality in Europe – 2016 report" approximately 1600 Norwegians died prematurely in 2013 due to exposure to $PM_{2.5}$ emissions. The corresponding number for NO_2 was 170 (EEA, 2016; NILU, 2016).

MEASURED VALUES OF AIR POLLUTION

Haugsbakk and Tønnesen (2010) did a measurement of PM_{10} and NO_2 concentration in Geiranger Centre by the ferry dock. Measurements were made consciously from July to September 2010. Results from the study show two occasions of PM_{10} exceeding the threshold level of 50 $\mu g/m^3$. There were no exceedances of NO_2. Löffler (2017) did measurements of SO_2, PM_{10} and $PM_{2.5}$, concentrations in the air in Geiranger from June 2015 to September 2016. SO_2 concentrations were measured with hourly maxima below 10 $\mu g/m^3$ for the entire duration of measurement. Löffler and his team found relatively high concentration of PM_1 and deemed this as the major pollutants in the Geiranger area. Six exceedances of $PM_{2.5}$ over the threshold level of 25 $\mu g/m^3$ were observed. There was also a correlation of high PM_1 concentrations and relatively high SO_2 concentration, making it plausible that the PM_1 emission originate from combustion of petroleum products, although no definitive conclusions were made. It was also observed that the PM fraction is suspended in the air over many weeks and is transported by circulating air along the entire valley, apparently being trapped by a combination of the local topography and special weather conditions.

ESTIMATED VALUES OF AIR POLLUTION

Weggeberg et al., (2017) chose a theoretic approach to estimate the concentration of NO_x, $PM_{2,5}$, PM_{10} and SO_2 in the Geiranger area. Based on vessel information from AIS system on movement and IHS Fairplay data for machinery the emissions from shipping were calculated. Together with statistical data from road traffic the emissions from sea and land transport were fed in to a CALPUFF model. The CALPUFF model is a modeling system for the simulation of atmospheric pollution dispersion. Results from the analysis show only one occasion of NO_2 emissions exceeding the one hour threshold level of 200 $\mu g/m^3$. The report suggest that one hour threshold levels should be the benchmark for Geiranger due to the fact that the activity and emissions are condensed within a few months in the summer making annual mean values less relevant. Some occurrences of emissions of $PM_{2,5}$ in the area around 20 $\mu g/m^3$ were also observed in Geiranger Centre (ibid.).

Emission of NO_2, PM_{10} and $PM_{2,5}$ from road traffic in Geiranger was calculated on the basis traffic statistics and emission factors for road vehicles. Combustion of diesel and gasoline together with abrasion of the road from the tires and brakepads contribute to the emissions. The results of the calculations of two studies made in recent years are given in table 1:

Table 1: Emission of NO_x, PM_{10} and $PM_{2,5}$ from road traffic in Geiranger

Study	**Area of focus**	**Emissions from road traffic [tonnes]**		
		NOx	PM_{10}	$PM_{2.5}$
Weggeberg et al., 2017	Estimated NOx $PM_{2.5}$, and PM_{10} emissions from road transport in Geiranger from June to August 2016.	1.75	0.066	0.052
Shlopak et al., 2014	Estimated NOx and CO_2 emissions from road transport in Geiranger for the year 2013.	2.93		

Cruise ships provide accommodation and leisure services throughout their journeys in addition to provide transport for up to 6000 guests and 2000 crewmembers. The ships have many engines on board that allow for flexible operation and electricity generation at varying power requirements. A survey to cruise operators in the Geiranger fjord in 2016 show that 36% of cruise ships operating in Geiranger have direct mechanical propulsion and 64% have diesel electric propulsion (Stenersen, 2017). Nominal engine speeds of the engines are in the area 400-600 rpm and total installed power range from a few MW on the smallest ships to 120 MW on the biggest ship. There is a linear correlation between ship size in gross tonnage (GT), total installed power and passenger capacity (PAX). Ships maneuvering or at berth/anchor in Geiranger report a normal distribution around a mean of around 50% engine load. The mean time at berth in Geiranger is 6-8 hours (ibid).

Marine diesel engines are able to use a variety of fuel oil qualities. The quality of the fuel affect emissions ranging from high sulphur containing heavy fuel oil (HFO) to low sulphur fuels like marine gas oil (MGO). The cost of fuel is higher in low-sulphur oils than residual high sulphur oils. High sulphur content in fuel give high emissions of sulphur oxides and particulate matter. 70% of cruise ships operating in Geiranger in 2016 used MGO (<0.1% Sulphur content) for main- and auxiliary engines (Stenersen, 2017). After the exhaust gases are emitted into the air from the ship stacks they are diluted in the ambient air. During the dilution process they are partly chemically transformed or removed (Eyring et al., 2005). Nitrogen oxides (NO_x) are formed when combusting fossil fuels at high temperatures. Emissions of NO_x and PM have local effects like air pollution and smog formation, having an effect on human health. It is estimated that, globally, 30% of smog comes from ships (Miola et al., 2010).

In addition to replacing high-sulphur fuels with low-sulphur fuels there are mainly three main emissions abatement technologies available for marine diesel engines; exhaust gas scrubbers for SO_2 and PM reduction and Selective Catalyst Reduction (SCR) and Exhaust Gas Recirculation (EGR) for NO_x reduction. Although 20-25% of respondents to the survey by (Stenersen, 2017) state they have NO_x abating technology installed, only two of the ships responding declared they were compliant to IMO Tier III levels. Sulfur emission requirements can be met either by using low sulfur fuel or by cleaning exhaust for sulphur. About 25% of ships operating in Geiranger state that they have installed scrubber systems to reduce SO_x emissions (Stenersen, 2017).

Due to regulations being implemented in recent years an increasing share of cruise ships are built with emission abatement technologies where 49% of new global passenger capacity is based on LNG for primary propulsion (CLIA, 2020). The challenge for Geiranger is that the mean age of ships operating in the area not renewing at a rate which is fast enough to meet many of the coming regulations (see figure 3). Any regulations capping emissions from ships will have accompanying costs to the ship-owners if re-builds of the marine power generating systems are needed in order to comply.

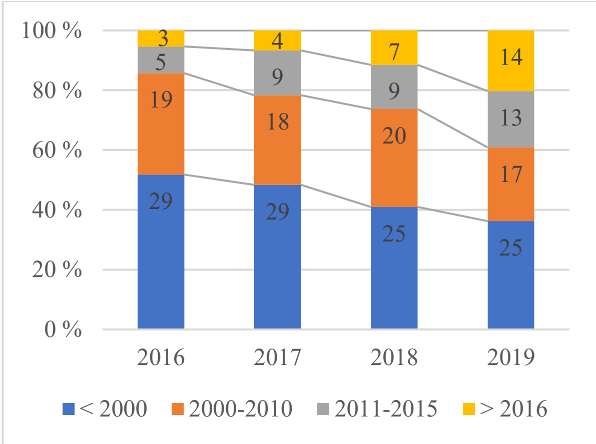

Figure 3: Share of cruise ships calling to Geiranger built according to MARPOL Appendix VI Tier levels. (Based on itinerary data from Stranda Port Authority)

In recent years two substantial assessments on the environmental impacts from seaborne transport in Geiranger has been conducted; Svendsen et al., (2015) and Weggeberg et al., (2017). Both follow a bottom-up approach where data on movement and number of ships were collected. Operation characterization for the ships were set up based on collected technical information like ship size, main engine type, auxiliary engine type, type of fuel etc. Emissions were then calculated combining activity data and technical data for the ships. The discrepancy between estimated values of NO_x between the two studies is due to different systems boundaries both in time and geography. The large relative contribution from cruise ships make it reasonable to consider subjecting further regulations to cruise ships as an effective action to reduce emissions in Geiranger (NMA, 2017).

Table 2: Estimated NO_x, $PM_{2.5}$, and PM_{10} emissions from sea transport in Geiranger

Study and area of focus	**Emissions from sea traffic [tonnes]**		
	NOx	PM_{10}	$PM_{2.5}$
Weggeberg et al., 2017; Estimated NO_x $PM_{2.5}$, and PM_{10} emissions from sea transport in Geiranger from June to August 2016.	67.9	2.15	1.97
Share of total emissions from mobility in Geiranger attributed to cruise ships	81%		
Svendsen et al., 2015; Estimated NO_x $PM_{2.5}$, and PM_{10} emissions from sea transport in Geiranger from June to August 2016.	203	2,85	
Share of total emissions from transport in Geiranger attributed to cruise ships	94%	94%	

REGULATIONS

Air emissions from ships is regulated by MARPOL Annex VI. The convention contains provisions controlling emissions of NO_x, SO_2, PM, VOC and ozone depleting substances as well as waste incineration on board, repairs and the quality of fuel. MARPOL also defines specific emission control areas (ECA). The International Maritime Organization (IMO) has put a cap on sulphur content in fuels used on board ships to 3.5% m/m. In emission control areas (ECA) the sulphur content is capped at 0.1% m/m (imo.org). Reducing sulphur considerably reduce emissions of SO_2 and PM, but also NO_x by around 5% (Cooper and Gustavsson, 2004). Air emissions are of particular interest to EU countries and therefore the EU Directive 2005/33/EC requires that all ships in European ports use fuel with low Sulphur content of 0.1%, this is much more stringent than the MARPOL standard of 3.5%. The implementation of directive 2005/33/EC has had a noticeable effect in reducing SO_2 in some European ports (Schembari et al., 2012). The NO_x-emission limits introduced by IMO apply to marine diesel engines and depend on an engine's operating speed. Requirements in Tier I apply to ships built after 2000, while the stricter Tier II limits apply to ships built after 2011. In emission control zones, Tier III requirements apply to ships built after 2016. A Tier III compliant ship will have about 74% less NOx emissions than a Tier II ship (Martinsen and Torvanger, 2013). Tier I and Tier II are global requirements, whereas Tier III standards only apply to current existing ECAs in North America and the North Sea and Baltic sea in 2021 (imo.org).

Table 3: Proposed regulatory actions for the Norwegian World Heritage Fjords (NMA, 2017)

	Proposed reguatory action
R1	Requirement for ships to have NO_x emissions not exceeding values given in MARPOL Appendix VI, 13.4 (Tier II) within 2018 and 13.5 (Tier III) by 2020
R2	Only allow use of low-sulphur fuel oil within the World-Heritage fjords
R3	Introduce requirement for ship smoke opacity. 50% at start-up and 10% for steaming
R4	Mandatory environmental reporting for all ships operating in the World-Heritage Fjords
R5	Limit number of port-calls and consider long-term operation licenses for Cruise lines with strong environmental limits
R6	Introduce speed limits for given parts of the fjords.

Maybe the most ambitious measure suggested by NMA is to demand ships operating on the World Heritage Fjords to comply to MARPOL Anenx VI, part 13.4 (Tier II) by 2018 and part 13.5 (Tier III) by 2020 (R1)(NMA, 2017). The study made by Stenersen (2017) found that 18% of ships operating in Geiranger in 2016 achieve at least Tier II level while only 6% are Tier III. Emissions of NO_x and PM could be reduced by using low Sulphur fuel oil, but mitigating NOx requires costly alterations in the engine room either by re-building engines, installing new engines or installing SCR systems (NMA, 2017). In addition to R1 entering in to force, the Norwegian parliament also set requirements for government to introduce regulations requiring zero-emission shipping in the World Heritage Fjords by 2026 (stortinget.no).

IMPLICATIONS OF NEW REGULATIONS

There is a large body of literature discussing stakeholders. An often-cited definition of stakeholder is given by Freeman (1984). Stakeholders to tourism mobility system in Geiranger and their perceptions are in the process of being mapped in the research project SUSTRANS (www.sustrans.no). Stakeholders' valuations of different criteria diverge and therefore the task of making the right decisions, suiting the needs and expectations of stakeholders becomes challenging. Measure of effectiveness (MoE) is a term describing the realization of a system (NASA, 2007). The obvious logistic aspects of the tourism mobility system in Geiranger needs to be realized, but there is an available solution space when "designing" the transport system that would give different solutions suiting different demands. Decision makers need to design the transport system, within the scope of the upcoming environmental regulations for ships operating on the World Heritage Fjords. The following measure of effectiveness (MoE) is suggested based on the "*Big picture*"-project by the local municipality (stranda.kommune.no), focusing on the future of tourism within the scope low- and zero emission seaborne tourist mobility: "*Economic, social and environmentally sustainable tourism industry in the Geiranger fjord and adjacent area beyond 2026.* " The assessment of several competing aspects in context of decision making is often referred to as Multi Criteria Decision Analysis (MCDA) (Belton and Steward, 2002). One of the simpler methods within MCDA is by using decision matrixes. In order to get the full view of the possibilities decision makers have, an extensive survey should be made exploring infrastructure epochs in combination with new regulatory regimes where quantifying the effects and perceived stakeholder valuation of initiatives for reducing emissions is one of them. The evaluation of regulatory actions with assessment of emissions abatement and perceived stakeholder valuations discussed in the earlier sections could be summarized in an objectives hierarchy. The objectives hierarchy which aims to rank the different decisions in a risk management setting (NASA, 2007). A proposed simplified objectives hierarchy structure for the case of reducing emissions to air and improving air quality in the Geiranger Fjord is given in figure 4.

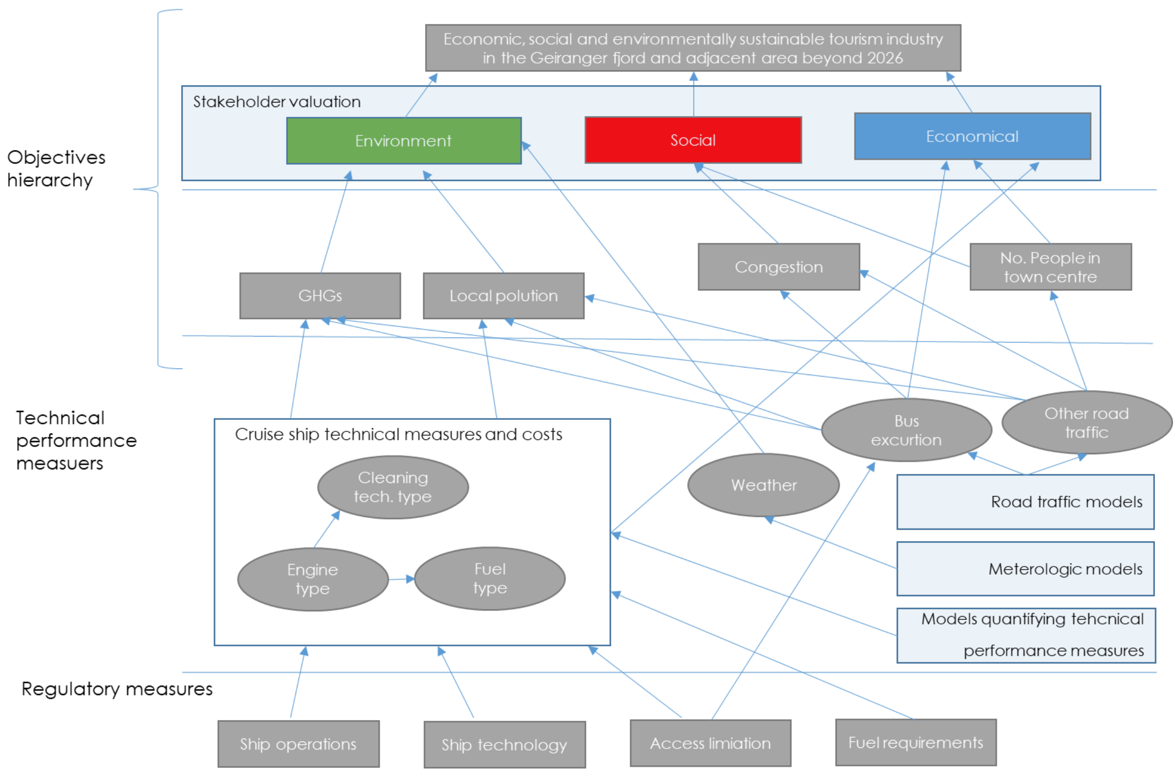

Figure 4: Example of Objectives Hierarchy, Technical Performance Measures and Regulatory Measures for Future Zero Emissions Sea Based Tourism Mobility in the Geiranger Fjord Area

The elements in the system are: a) sensitive to changes in regulation, b) to a varying extent dependent on each other, c) with different perception of utility among stakeholders, d) with varying preference among stakeholders. Regulatory measures will require technical performance measures in order to achieve compliance. With regards to cruise ships the technical performance measures could either be made through investment in cleaning technology as SCR/EGR or scrubbers or through change in operations as slow speed, limitations of port calls and choice of fuel. These measures are the least cumbersome to make reliable estimates of with regards to the measures' direct effect on the emissions. The trouble is to find the indirect effects that imposing these measure will have on the rest of the transport system and the different stakeholders' appraisal for the outcome for the environmental, social and economic criteria. One example which is discussed in relation to the Geiranger Fjord area is that if regulations on ships are too strict, then this will reduce the number of cruise calls and more tourists will arrive by bus instead and increase traffic congestion. Another example is if access limitation is introduced, this might reduce emissions and traffic, but would potentially reduce economic output.

DISCUSSION AND CONCLUSION

Both MCDM and systems thinking methodology require decision making to put into the proper context. "Who is the decision maker?" is according to MCDM methodology one of the first questions to ask when analyzing a decision process while in systems thinking one might ask who are the ones influencing and being affected by the system where decision are made? Both views are important to follow and in a systems thinking manner it is important to firstly understand the dynamics behind the elements of the systems being managed or considered for some act of change making. How will management or change influence the different stakeholders of the systems? Will the decision have the desired effects on the impacts of sustainability? Will the decision provide a balanced solution within all three dimensions of sustainability? These are important questions to guide the decision process. One formal decision maker in relation to cruise tourism destinations that both has a formal mandate and responsibility for its surroundings and stakeholders is the local municipality and subordinate port operation organization. The alternatives in future assessments should be analyzed and expressed with sustainability criteria and performances and the decision makers should provide with a weighting of the different criteria.

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