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Research Article

Emission and environmental cost estimation of ferries operating in Lake Van

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Abstract

Ships, which are the essential elements of maritime transportation, have an indispensable role in world freight and passenger transportation. Besides sea routes, the role played by ships in inland water transport is also very important. In addition to these important economic effects, ships are also a major pollutant source. These emissions have negative effects on human health, cities, and the environment, as well as causing atmospheric pollution. Lake Van is Turkey's largest inland lake, with an area of 3,713 km^2, and is an important inland waterway, with an active ferry network operating between Van and Tatvan-Bitlis. In this study, emission calculations of these ferries operating in Lake Van were carried out; it was aimed to develop an emission inventory for ship-related air pollution on Lake Van. Additionally, the environmental (social) costs of these emissions were estimated to assess the total impacts. One year of ship operation data was used for the calculations, and the engine power method was preferred, according to the available data. According to the calculations, the ship-originated emission inventory on Lake Van was determined to be 36,140.54, 107.84, 29.15, 17.49, 990.95, and 11.66 t for CO_2, SO_2, CO, HC, NO_x, and PM, respectively. The total environmental costs of these emissions were calculated to be 40,046,340 €. These results are important in terms of determining the environmental effects of transportation activities in Lake Van, which have not been studied before.

1. Introduction

1.1 Background of the study

Ships are very important tools of transportation, accounting for 80 to 90 % of the total world trade (UNCTAD, 2020). Although maritime transport is more sustainable and economical than rail and road transport, it causes significant environmental emissions of greenhouse gases (Medda & Trujillo, 2010). It is estimated that about 450 different atmospheric pollutants are generated as a result of burning fossil fuels in internal combustion engines in ships (Kollamthodi et al., 2008). The most important of these pollutants, in terms of quantity and damage, are carbon dioxide (CO_2), sulfur dioxide (SO_2), carbon monoxide (CO), unspecified hydrocarbons (HC), nitrogen oxides (NO_x), and particulate matter (PM). Of these, CO_2 contributes to global warming (Houghton et al., 1990; Smith et al., 2014) and ocean acidification (Doney et al., 2009; Millero, 1995; Raven et al., 2005); NO_x contributes to ground-level ozone formation and acid rain (Andreoni et al., 2008; Haglind, 2008; Kågeson, 1999); SO_2 contributes to acid rain and harmful effects on human health (Andreoni et al.,

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2008; Haglind, 2008; Kollamthodi et al., 2008; Wang et al., 2007), and PM contributes to global warming (Capaldo et al., 1999; Eyring et al., 2010; Lauer et al., 2007; M. Schreier et al., 2006; Mathias Schreier et al., 2007) and premature deaths (Agarwal, 2009; Corbett et al., 2007).

1.2 Literature review

Although greenhouse gas emissions were seen as "conditional marine pollution" in previous years, national and international agreements have brought stricter rules with increasing awareness (Shi, 2016). To keep global warming below 2 °C, it is necessary to reduce the emissions from maritime transport as much as possible and keep them under control (Wan et al., 2018). Since these harmful effects are well known, intensive efforts are made to reduce ship emissions through effective restrictions applied on a global and regional scale. For this purpose, the coasts of the USA and Canada, as well as the Baltic Sea and the North Sea regions, have been declared as Emission Control Areas (ECA), and the coasts of the European Union (EU) have been subject to serious restrictions, especially on SO_2 and NO_x emissions, with various EU directives. Despite the existence of these studies for the marine environment, regulations on inland waters are less frequent, and it is an important step for China to include the Yangtze and Xi-Jiang Rivers in its emission restriction area, in addition to its territorial waters, by 2020. In addition to emissions that have direct effects on human health, such as PM, SO_2, and NO_x, the International Maritime Organization (IMO) has conducted intensive and effective studies on reducing CO_2 emissions. IMO aims to reduce greenhouse gas emissions from ships by 40 % by 2030, and by 70 % by 2050, compared to 2008 (Christodoulou & Echebarria, 2021; IMO, 2018).

Christodoulou et al. stated in their study that the tax to be applied according to the emission values of ship fuels will be an important factor in reducing greenhouse gas emissions (Christodoulou et al., 2021). Brynolf et al. investigated various combinations to reduce NO_x and sulfur emissions from maritime transport. These combinations were (1) heavy fuel oil (HFO) combined with selective catalytic reduction (SCR) and scrubber, (2) marine gas oil (MGO) combined with SCR, and (3) liquefied natural gas (LNG). These identified combinations were evaluated using life cycle assessment (LCA). When evaluated within the scope of life cycle analysis, it was seen that none of the alternatives was more effective on climate change than HFO. They also reported that the use of SCR in Swedish waters was used to reduce NO_x emissions (Brynolf et al., 2014; Cullinane & Bergqvist, 2014). Gagatsi et al. stated that short and medium-range electric ferries operating with 99.7 % recyclable batteries used in inland waterways can eliminate CO_2 emissions (Gagatsi et al., 2016). Another study on Swedish ferry lines showed that providing electrification on ships is important in terms of reducing ship-sourced greenhouse gases. In the study, it was stated that the transition to an electric system during maneuvering in ports contributes to 500 t less fuel consumption and 1,500 t fewer CO_2 emissions, which is equivalent to the emissions of approximately 600 cars (Christodoulou & Cullinane, 2021).

Although ship activities in inland waters such as lakes and rivers are naturally much less compared to activities carried out at sea, the detection of these emissions is an important issue, as the emissions generated as a result of these activities are at a level that can directly affect living areas.

One extensive study on the generation of ship-related emissions in inland waters targeted the Grand Canal in China. It has been observed that the CO, HC, and PM production of ships moving in maneuver mode in the channel is intense, and that larger size PM is produced. Similarly, NO_x production is higher than international standards (Fu et al., 2013). Another study conducted in the Netherlands showed that, although inland water transport accounts for 30 % of total transport in Dutch waters, it was responsible for 80 % of total emissions. The most important pollutant caused by inland water transport is black carbon (BC), and the amount of BC produced was determined to be 0.5 µg elemental carbon (EC)/m^3 (Keuken et al., 2014). In another measurement made in Germany's Rhine and Moselle Rivers, the production of ship-related polycyclic aromatic hydrocarbons (PAH) was determined by measurements obtained from the soil near the river. Accordingly, while the amount of

PAH near the Rhine was 581±252 ng/g, the amount of PAH measured in the Moselle Valley was 1,543±788 ng/g (Bläsing et al., 2017). In a study conducted for the Yangtze River in China, it was measured that the ratio of PM emissions from river transport to total PM emissions was 4 %, and this ratio rose to 35 % in ports on the river. In addition, it has been observed that ship activities are an important SO_2 and NO_x producer (Chen et al., 2019). In another study conducted on the Yangtze River, it was observed that the concentration of ship-related PM emissions reached 4.62 μg/m^3, especially in the summer monsoon season (Feng et al., 2019). In a more recent study for the Yangtze River, CO_2, CO, SO_2, NO_x, $PM_{2.5}$, PM_{10}, and HC emissions due to inland waterway transportation in the river in 2018 were measured as 5.67×10^5, 1.02×10^3, 5.41×10^2, 1.06×10^4, 2.43×10^2, 2.45×10^2, and 3.52×10^2 t, respectively (Huang et al., 2022). In a study conducted for the estimated emission amount in the port area in 2030 for ship traffic to the Port of Gothenburg, three different scenarios were developed- "Alternative fuel", "Ship design", and "Operation"- to reduce the number of emissions. Among these three scenarios, in the "Operation" section, the reduction of speed and waiting times at the quay were determined to be the factors that reduced the amount of emissions the most (Winnes et al., 2015).

As can be seen from the literature review, the environmental impacts of inland waterway shipping have often been overlooked because inland shipping activities are much less than those at sea. Transportation activities in and around the Yangtze River were evaluated throughout the studies. Only one master's thesis has been found in the literature on an important waterway such as Lake Van, and the evaluation of this study will be done in the Discussion section. Lake Van is very suitable for transportation as a large body of water, and there is a ferry line between Van-Tatvan/Bitlis that is in operation. The main purpose of this study is to examine the emissions caused by the ferry operation and the environmental damage of these emissions in detail.

In this context, this study is seen as the first to calculate the emissions resulting from ferry activities in Lake Van according to the engine power method. On the other hand, it is the first study to calculate the environmental effects of these emissions. Accordingly, the results of the study fill a gap in terms of determining the holistic effects of emissions and of putting into effect emission reduction measures which are important in this respect.

2. Materials and methods

2.1 Data analysis

Lake Van is a volcanic barrier lake and is a unique water body, both geographically and hydrologically. Lake Van is the largest lake in Turkey (and the Middle East excluding Lake Hazar), large enough to be called 'sea' by the local people, and is also used as an important transportation route due to this feature. Ferries operating between Van and Tatvan-Bitlis are important parts of the trade between Turkey, Iran, and Central Asia, as well as human transportation. **Figure 1** shows the route of these ferries on Lake Van.

2.2 Research method

Calculations were made according to the engine power method; the formula for this method was proposed by the Intergovernmental Panel for Climate Change (IPCC), and is presented below (IPCC, 2006):

$$E_{Trip,ij,m} = \sum_p [T_p \sum_e (P_e \times LF_e \times EF_{e,i,j,m,p})] \quad (1)$$

where;

E_{Trip}: Total emission (t)
T: Voyage duration (h)
P: Engine power (kW)
LF: Load factor (%)

EF: Emission factor (g/kWh or g/MJ)
p: Voyage phases
e: Engine category
i: Pollutant type
j: Engine type
m: Fuel type

According to the information obtained from Van Lake Ferryboat Operations Directorship, the engine power of the ferries was 6,600 kW, and the annual total working hours were 11,040 hours, in 2020. The load factor is assumed as 0.8. The emission factors are presented below, in **Table 1**.

Figure 1 The route of ferries in Lake Van.

The cruising range is approximately 49 miles, the passenger capacity of the ferries is 350, and the daily carrying capacity is 10,500 t (Web1, 2022).

Table 1 Emission factors (Moldanova et al., 2010).

Emission Types	**CO_2**	**SO_2**	**CO**	**HC**	**NO_x**	**PM**	**Unit**
Emission Factors	620	1.85	0.5	0.3	17	0.2	g/kWh

Environmental (or social) costs are refer to environmental or human costs resulting from pollutants. Each pollutant leaves damage that needs to be repaired in the environment or body exposed to this pollutant. While this repair includes various cleaning processes for the environment, it includes hospital processes for people. Environmental (or social) costs are the costs incurred in the process of repairing these damages, the hospital costs, and the losses arising from the production power that the people in need of treatment cannot bring to society during the treatment. The environmental cost factors for various pollutants are presented in **Table 2**.

Table 2 Environmental cost factors (De Bruyn et al., 2018).

Emission Types	CO_2	SO_2	CO	NO_x	PM	Unit
Emission Factors	0.0566	24.9	0.0958	34.7	79.5	€/kg

3. Results and discussion

The obtained emission results are presented in **Table 3**.

Table 3 Emission amounts.

Emission Types	CO_2	SO_2	CO	HC	NO_x	PM	Unit
Emission Amounts	36,140.54	107.84	29.15	17.49	990.95	11.66	t

These emissions are the total amount generated over one year, and the values in Table 2 should be divided by 365 for the daily emission formation. Since the emissions are generated during the operation, their impact on the cities of Van and Tatvan is considered to be limited. However, the varying atmospheric conditions on the lake may cause emissions to harm other nearby settlements, agricultural lands, and aquatic life in the lake, apart from the mentioned cities. It has been calculated that these emissions cause a total environmental cost of 40,046,340.03 €, annually.

In a master's thesis based on the data of 6 ferries, 2 sea buses and 5 passenger ships operating in Lake Van, covering the years 1988-2020, an emission inventory of ship-related emissions in the lake was developed; it was concluded that, in the first 11 months of 2020, ships consumed a total of 2731.49 t of fuel. It was calculated that 2 ferries produced 8757.2 t CO_2, 154.9 t NO_x, 7.1 t CO, 3,742 t SO_x, and 2,458 t PM (Aygül Özcan, 2021). These values are considerably lower than the values found in this study, and it is thought that there are two reasons for this. (1) Although the fuel consumption and the engine power method are based on the same principles, the calculated values may also be different because they follow different paths and use different variables for emission calculations. This is a normal and expected result, and decision-makers can accept the results of both methods as correct, (2) Since the calculations made in the thesis cover the first 11 months of the year, there is missing data for one month. This is one of the reasons for the lower values.

In a recent study in which the emissions caused by land traffic in the city of Van were calculated, CO, NO_x, and PM emissions from city traffic were found to be 442.78, 83.01, and 8.01 t per year, respectively. When these values are compared to ferry emissions, it can be said that ship emissions cause more emissions other than CO (Yakın & Behçet, 2019).

In both cases, it is seen that the amount of emissions released is at a significant level. In addition, the environmental (social) costs caused by these emissions are more than 40 million Euros per year. For this reason, taking measures to reduce emissions is considered important for the environmental protection of the region.

4. Conclusions

Ships, which have an important role in domestic transportation, as well as in global transportation, are major sources of pollutants in addition to the benefits they give. As a result of the internal combustion process in ship engines, gas emissions, which are major components of atmospheric pollution, are produced. In addition to having various environmental effects such as global warming, ocean acidification, acid rain, and ground-level ozone, these emissions can have fatal consequences on human health.

It is known that emissions increase health problems and treatment costs, permanently damage agriculture and livestock activities, create a heavy environmental burden in sensitive aquatic and marine ecosystems, and cause indirect financial problems in cities. Emissions emitted by ferries

operating in Lake Van not only have negative environmental impacts on a regional scale but may also affect other nearby regions through atmospheric events. Emissions harm the agriculture and livestock capacity of the region and have the potential to damage the lake ecosystem where endemic species live. The calculated environmental (social) costs consist of all of these and indicate an annual economic loss of 40,046,340.03 €.

Although lakes and inland waters do not always have suitable conditions for waterway transportation, they offer important opportunities for the acceleration and diversification of transportation in the presence of large settlements around them. On the other hand, inland water transport is an issue of which its environmental impacts have not been studied well, even though it usually passes near densely populated settlements. Although the Danube and Rhine rivers, which have very heavy traffic, have been the subject of some studies, countries usually ignore the damage this transportation causes. This study contributes to the orientation of international researchers by examining the emissions of Lake Van, which is considered an important waterway. Transportation on Lake Van is not only on a local scale but is also considered important in terms of the lake's potential to serve as an important bridge between Europe and East Asia. China's One Belt One Road (OBOR) project may increase the importance of the lake, as well as contribute to an increase in the population of the region, increasing the capacity of local transportation.

In this context, IMO's rules for ships embarking on maritime operations are also recommended to be applied in inland waters, which are sensitive ecosystems that have more limited connections and, therefore, it is more difficult for them to clean themselves. IMO aims to reduce shipping-related CO_2 emissions by 40 and 70 % in 2030 and 2050, respectively. To achieve this target, inland waterway transportation should be considered with the same sensitivity as overseas transportation.

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