Transportation Research Part D 52 (2017) 254–276

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

Alternative fuel for sustainable shipping across the Taiwan Strait

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ARTICLE INFO

Article history:
Available online 21 March 2017

Keywords:
Energy use
Ship
Marine fuel
Life cycle
Taiwan Strait
Air pollution

ABSTRACT

We conducted a total fuel life-cycle inventory for atmospheric emissions for two ships operating between Mainland China and Taiwan, comparing the difference that may result from operating on heavy fuel oil (HFO) and on liquefied natural gas (LNG) as fuels. In addition, we assess the global warming impact from these two fueling alternatives. We use a commercially available life-cycle assessment (LCA) software to conduct a life-cycle inventory of airborne emissions from the ship fuel use. Our findings indicate possible improvement in total fuel-life-cycle GHG emissions from the use of LNG as alternative fuel to power ships. While total GHG and CO_2 emission reduced, however, methane emissions increased significantly when LNG is used as alternative fuel to power both of our case ships. Both ships exhibit great reduction in the emissions of NO_x (38–39%) and CO (42–43%). The reduction is much more remarkable in SO_2 (99.8%) and PM_{10} (97.5%). The weight of emissions from operation stage has become relatively smaller in the whole fuel life-cycle total GHG emissions, when the two ships move to operate on LNG.

1. Introduction

Marine shipping represents about 90% of international trade and is growing faster than the world's economy (Endresen et al., 2003, 2005, 2007; Lauer et al., 2007; GL, 2014). Although seaborne transportation is by far the most energy-efficient ways of transport (calculated in ton-miles) (Mortensen, 2009), there have been increasing concerns about the adverse human health and environmental impacts of atmospheric emission resulted from fuel combustion onboard ship (Endresen et al., 2003, 2005; Eyring et al., 2010). The situation is set to worsen in face of the growing globalization.

The effect of atmospheric emissions from marine shipping is a subject of concern for two main reasons. Some species in combustion exhaust, e.g., particulate matter (PM), especially with diameter smaller than 2.5 μm ($PM_{2.5}$), nitrogen oxides (NO_x), sulfur oxides (SO_x), are detrimental to human health and ecosystem. In particular, the priority concern lies in the high volume of shipping activities occurring in highly populated regions. Approximately 70% of ship-originated emissions occur within 400 km of coastlines, globally (Capaldo et al., 1999; Corbett et al., 1999; Winnes et al., 2010), causing environmental issues in coastal and harbors regions with busy traffic (Endresen et al., 2003, 2005; Eyring et al., 2010). In addition to PM, NO_x, SO_x, their derivative species such as volatile organic compounds (VOC) from marine vessels can transport over several hundreds of kilometers, contributing to air pollution inland (Corbett and Fischbeck, 1997; Corbett and Winebrake, 2007).

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http://dx.doi.org/10.1016/j.trd.2017.03.015
1361-9209/

Another concern for atmospheric emissions from ships is they contribute to greenhouses gases (GHGs), worsening anthropogenic climate change. Carbon dioxide (CO_2) emissions from marine shipping represent 3.3% of the world's total CO_2 emissions and are forecasted to increase by 150–250% by 2050, alongside the increasing trade volumes (IMO, 2013, 2014). Based upon study results from IPCC (2007), fulfilling anticipated climate goals requires shipping sector to reduce emissions per freight unit by a factor of five or six. In addition, ships emit other (non-gas) climate pollutants (e.g. black carbon) that are linked to climate changes, especially in the Arctic, and human health issues (Lack and Corbett, 2012).

1.1. Growing concern on emissions from shipping across the Taiwan Strait

The 50-year ban of direct cargo and passenger transport between Mainland China and Taiwan was finally lifted in December 2008. The direct cargo shipping between the Mainland China and Taiwan reached 111 million revenue tons and the container shipment volume was about 2.5 million TEUs in 2014 (MOTC, 2014). More than 1.7 million cross-Strait passengers entered and exited through Taiwan's international commercial ports in 2012, an increase of 5.2% compared with 2011 (MOTC, 2014). However, this rapid growth of shipping can lead to worsening environmental problems across the Strait.

China is home to 7 of the 10 busiest container ports in the world, measured by total annual throughput of containers (World Shipping Council, 2016). Pollutants generated by ships and the ports contributed to more than 50% of airborne pollution in Hong Kong and can reach as high as 20–30% for some major port cities in Mainland China (China Daily, 2014). In Shanghai and Guangzhou, concentration levels of $PM_{2.5}$ exceed WHO air quality guidelines of 10 μg/m^3 and 25 μg/m^3 for annual mean and 24-h mean, respectively (WHO, 2005; Tsai et al., 2012; Wang et al., 2016).

A survey conducted by World Health Organization (WHO) finds that shipping is one of the top three emission source categories of concern associated with emerging issues for public health (WHO, 2014). As much as 64% of primary $PM_{2.5}$ contributed by ships in Shanghai Port transporting to inland (Zhao et al., 2013). Average sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) concentrations in Shanghai Port were comparable with those in Shanghai city area (Zhao et al., 2013). Two common elements in marine fuel oil, Nickel (Ni) and vanadium (V) were found enriched in $PM_{2.5}$, and the concentration of V was highly correlated with ship fluxes (Zhao et al., 2013). In Taiwan, SO_x is the highest component of air pollution attributed to shipping, followed by NO_x, PM, and hydrocarbon (HC) (Hua, 2005). O_3 and PM are the two major air pollutants responsible for poor air quality in the largest port city—Kaohsiung (Tsai et al., 2012).

1.2. Emission reduction from marine shipping

Stakeholders ranging from international shipping companies and non governmental organizations to government bodies have expressed concerns about the environmental impacts caused by shipping-related activities (Fet, 1998; IMO, 2006, 2010). The International Convention for the Prevention of Pollution from Ships (MARPOL) was adopted by the International Maritime Organization (IMO) in 1973 to address the issue of pollution from ships. Annex VI of MARPOL was first adopted in 1997 to deal with air pollution from ships, specifically SO_x and NO_x. As shown in Fig. 1, IMO has further adopted a scheme for reduction of emissions of SO_x, requiring sulfur maximum content in marine fuels to drop from 4.5% to 0.5% by 2020 globally, and in the environmentally sensitive areas, so called Sulphur Emission Control Areas (SECAs), from 1% to 0.1% (IMO, 2010, 2014; US EPA, 2014; DNV GL, 2014). The 0.1% fuel sulfur limit in SECAs has already come into force since January 1, 2015 (IMO, 2016a). IMO expect the revised measures to have a significant beneficial influence on both environment and human health (IMO, 2016b).

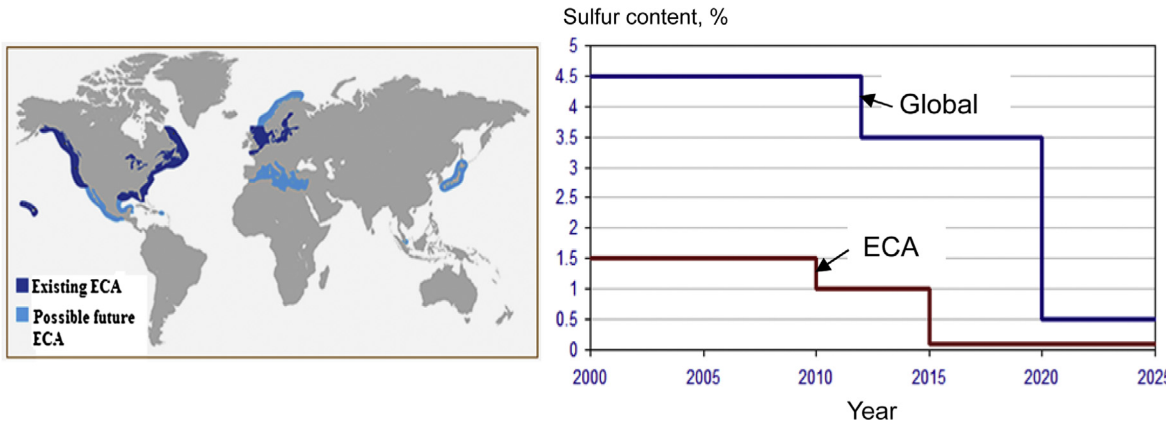

Fig. 1. Reduction limits of sulfur content in marine bunker for ships operating globally and in the ECA (shaded areas on the right). Adopt from IMO, 2014 and US EPA, 2010.