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Health costs and economic impact of wind assisted ship propulsion

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ABSTRACT

World seaborne transportation is crucial for world trade and global economic growth. Shipping has been increasing since 2009, including oil & gas, dry bulk and container freight, and is very likely to continue this trend in the near future. However, international shipping also produces 2.7% of the world's total CO2 emissions, and globally, air pollutants emitted from international shipping are increasing due to the rise in trade. It is a well-established fact that Greenhouse Gasses (GHGs) cause climate change and that air pollutants trigger a range of health issues for humans. To demonstrate the applicability of the proposed framework, this paper will focus on a general assessment of the health-related externality of air pollution emitted from wind-assisted hybrid ship propulsion within two different emission reduction scenarios. The paper will further analyse the emission impact from both individual scenarios. A Chemical Transport Model (CTM) is used to estimate the realistic concentration of relevant air pollutants, and the Economic Valuation of Air-pollution Model (EVA) is applied to assessing the health-related economic externalities of air pollution.

1. Introduction

World seaborne transportation is crucial for world trade and global economic growth. Shipping has been increasing since 2009 (Clarkson, 2016), including oil & gas, dry bulk and container freight, and is very likely to continue this trend in the near future.

However, international shipping also is the source of air pollutants such as NO_x, SO_2 and Particulate Matter (PM) (Eyring et al., 2010; Richter et al., 2004). Globally, air pollutants emitted from international shipping are increasing due to the rise in trade. Also in Europe, the shipping sector is a relevant contributor to ambient air pollution (Matthias et al., 2016, 2010). In contrast, anthropogenic land-based emissions of air pollutants have been considerably decreased in the past three decades (EMEP, 2015; Smith et al., 2011). It is a well-established fact that air pollutants trigger a range of health issues for humans (Brunekreef and Forsberg, 2005; Brunekreef and Holgate, 2002; Kampa and Castanas, 2008). In addition, coastal ecosystems and urban areas within close vicinity of shipping routes are particularly affected by shipping related air pollutants. Therefore, it is crucial and urgent to invest in low emission shipping in terms of both environmental and public health point of views.

Ezzati et al. (2002) showed that air pollution in the urban environment is estimated to cause 1.4% of all premature deaths and 0.5% of all disability-adjusted loss of life years. Additionally, the emission of PM is responsible for increased mortality and morbidity, causing 3% of adult deaths by cardiovascular and respiratory diseases. Approx. 5% of lung and trachea cancer is also attributed to PM air pollution (Cohen et al., 2004). In Denmark, atmospheric pollution causes approx. 3500 premature deaths annually (Brandt et al., 2013a). International shipping is, furthermore, a major contributor to air pollution levels in Europe as a whole, causing approx. 50,000 premature deaths per year (Brandt et al., 2013b).

In the coastal regions of Europe, shipping has a relatively higher contribution to air pollution then on the European average, which is why the relative health benefits and subsequent reduction of external health costs by reducing ship emissions were expected to be considerable higher. One measure to reduce these emissions is using wind propulsion devices, such as sails, in addition to conventional propulsion by combustion engines and propeller (Lloyd's Register Marine, 2015; Mofor et al., 2015). This concept is denoted as hybrid wind-assisted propulsion (WASP).

Consequently, the EU, IMO (International Maritime Organization) and WHO (World Health Organization) have adopted directives and

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guidelines that set out air pollution limit values to minimise the impact on human health (EU, 2000, 2008; IMO, 2005; WHO, 2006). Emission control areas (ECAs) came into force with MARPOL Annex VI, which set limits on the emissions of air pollutants such as sulphur oxides in sulphur emission control areas (SECAs). The Baltic Sea and North Sea are declared as SECAs. To comply with the ECA regulations of IMO, low sulphur fuels, emission abatement technologies and LNG as an alternative fuel have already been adopted by the shipping industry. Each option, however, is associated with different advantages and disadvantages. Selecting the best solution for compliance is a great challenge that shipowners and decision makers are facing today in the shipping industry (Ölçer and Ballini, 2015).

Due to the stringent environmental regulations, relevant stakeholders of the seaborne transportation industry have started to consider other ways than the mentioned abatement systems and alternative fuels to comply with IMO regulations and become more environmentally friendly. One promising direction is to decrease the fuel consumption of ships by increasing energy efficiency. Additional alternative is to employing renewable energy means on board of ships using innovative technologies and best practice. Once fuel consumption is decreased, externalities and the negative consequences of air pollutants resulting from shipping are reduced (Ballini and Bozzo, 2015; Ballini, 2015, 2013).

Energy efficiency improvement has been a well-established area since the 1970s, while renewable or clean energy use on board ships is a relatively new and growing field. When it comes to renewable energy employment, there are mainly two options to consider: wind and solar energy. Commercially sized merchant vessels cannot solely be propelled by wind or solar power. However, these energy sources can contribute to overall energy efficiency through hybrid propulsion systems, combining renewables and traditional fuel.

It should be noted that vessels have, indeed, previously been propelled by wind energy for many centuries. Wind energy has in the recent years regained a new momentum and popularity. Compared to other renewable solutions, wind energy has the advantage of being always available in open sea (Talluri et al., 2016).

Several research projects have studied the potential of fuel savings through the use of wind energy on vessels (Lloyd's Register Marine, 2015; Mofor et al., 2015).

According to Smith et al. (2013), 10–50% fuel saving is achievable from wind energy despite the fact that there is a wide spectrum of barriers for the uptake of wind energy in the shipping industry (Rehmatulla et al., 2015). According to Talluri et al. (2016), the ability of the vertical axis wind turbine (VAWT) to adapt to any wind direction may be considered most advantageous when compared to all the other wind-assisted technologies for marine propulsion, and hence, makes it ideal for utilisation in locations with highly variable wind directions.

Impact studies on the use of wind-assisted propulsion systems on ships have until now mainly been limited to the assessment of air pollution and fuel savings. Limited studies have been undertaken on sail-assisted ships (Shukla and Kunal, 2009; Lambrecht et al., 1994) fitted with horizontal-axis wind turbines combined for marine propulsion (Bockmann and Steen, 2011) and (Talluri et al., 2016) or vertical axis wind turbines fitted on the deck of a ship in conjunction with conventional power supply.

The aim of this research, however, is to assess the health-related economic externalities of air pollution (ambient atmospheric concentration) resulting from use of hybrid wind-assisted ship propulsion by considering two different emission reduction scenarios. The model applied for this purpose is the Economic Valuation of Air pollution Model (EVA; Geels et al., 2015; Anenberg et al., 2015; Brandt et al., 2011; 2013a; b)).

The paper is structured as follows: chapter 2 presents the methodology chosen and applied (EVA model). This is followed by the case study in chapter 3. Chapter 4 discusses the results and the study is concluded in the last chapter.

2. Materials and methods

2.1. The integrated health impact assessment model system, EVA model

In recent years, extensive measures have been adopted by authorities to remove harmful compounds from fuel (e.g. lead, benzene and sulphur from petrol and diesel) as well as to reduce emissions of air pollutants (e.g. fine PM and NO_X) with significant positive impacts on air pollution levels from local sources.

However, remote emissions, such as NO_X, SO_2 and PM from sea transport and industry, can be transported in the atmosphere over long distances contributing to local air pollution. Additionally, harmful compounds, such as sulfuric acid, nitric acid and secondary PM, are formed by chemical reaction during the transport. Therefore, remote emission sources can have even greater impact on human health and the environment than local emissions.

This paper applies the EVA modeling system that offers a detailed analysis of health-related externality costs. In contrast to previous publications, the health assessment module is coupled with the chemistry transport model CMAQ (Community Multiscale Air Quality) (Byun and Schere, 2006). This setup has the advantage over other approaches by describing non-linear processes using a comprehensive and thoroughly tested chemical transport model for calculating how specific changes in emissions affect air pollution levels.

The EVA model allows us to study differentiated scenarios to estimate the external heath cost of emissions from specific sources or sectors (called SNAP categories) within specific geographic regions within a given year. Using the so called "tagging" method, all scenarios are calculated individually assuming non-linear atmospheric chemical transformations and feedback mechanisms (i.e. without adopting the linear extra-/interpolation of standard reductions as used by the RAINS-Regional Air Pollution Information and Simulation, GAINS-Greenhouse Gas and Air Pollution Interactions and Synergies system. Alcamo et al., 1990, Klassen et al., 2004.

This paper specifically applies the integrated EVA modeling system to calculate the health-related economic externalities of air pollution from shipping emissions. The concept of the EVA system (Brandt et al., 2013a, 2013b; Geels et al., 2015) is based on the impact pathway.

The EVA system includes 18 different health outcomes (both morbidity and mortality) with associated economic valuation (see Table 1) related to health impacts from $PM_{2.5}$, O_3, SO_2 and CO. The $PM_{2.5}$ consists of the primary particles (black carbon and mineral dust) as well as the secondary inorganic aerosols (SIA). Impacts from O_3 can be counted as both positive and negative since O_3 can both be produced and removed as a result of non-linear atmospheric chemistry due to NO_x and VOC chemistry. All exposure-response functions used in the system have been reviewed and documented in literature. See Brandt et al. (2013a) for a full description of the model system.

2.2. Wind propulsion devices and expected emission reductions

The use of wind propulsion devices as means to reduce fuel consumption and emissions of ships are in the focus of this publication. The word 'sails' will be partly used in the sections below, because it is more compact than 'wind propulsion device' and easier to read. However, it has to be emphasized that different types of wind propulsion devices have been developed in the past century, which partly differ considerably from the classical sails. Examples these wind propulsion devices are wing sails, Dyna Rigs (modern square rig), Flettner rotors, and kites. A detailed description on these and further devices is given in Lloyd's Register Marine (2015), Mander (2017), Mofor et al. (2015), and Schwarz-Röhr et al. (2015).

In the paragraphs below, important aspects on wind propelled ships are summarized first. The summary shows why estimating reductions in fuel consumption and in emissions for a fleet of ships is not trivial. Then a brief literature overview on publicly available research on modern wind