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Abatement of air pollution at an aegean island port utilizing shore side electricity and renewable energy

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ABSTRACT

The air pollutant emissions of the ships at port represent a small percentage of the overall emissions from shipping however they are concentrated in a small area. In Mytilene, Lesvos, the port is located within the city limits, resulting in air pollution, congestion and noise, especially during the tourist season. The aim of this study is to estimate the quantities of particulate matter and CO_2 emitted by ships in the port of Mytilene and to explore the potential of shore side electricity to reduce the emissions. The emissions were estimated using the bottom–up methodology, based on the activity of the ships in the port (berthing, maneuvering). Simulation of renewable energy sources was made using Homer Energy microgrid simulation software. The results showed that between the 10th and 20th of August 2012, there were 40 calls of passenger ships, tankers and bulk carriers in the port of Mytilene, emitting 441 kg of PM_{10} and 282 metric tonnes of CO2. About 63% of PM_{10} and 77% of CO_2 were emitted at the berthing phase and the remaining during the maneuvering. These emissions could be reduced by providing electricity to the ships from a hybrid renewable energy system with wind turbines and photovoltaics, connected to the grid. Simulations showed that the total energy requirements of the ships in the port of Mytilene could be covered by four 1.5 MW wind turbines combined with a 5 MW photovoltaics. With this configuration, renewable energy will exceed the ships' electricity needs for most of the time in order not to increase the power station's load. The excess energy could be fed to the islands' grid, so a costly battery storage system is not necessary to handle the variations of alternative energy. In this way, a considerable reduction of the CO_2 and PM_{10} emissions by the ships in the port occurs, providing a viable solution for a cleaner and healthier environment.

1. Introduction

The air pollutant emissions of ships while they are at ports make up a small fraction of the overall emissions from shipping [1]. However, ports attract shipping traffic and form sources of concentrated exhaust emissions near populated areas. As a result the impacts of port emissions on public health are higher compared to the impacts of seagoing shipping [2]. Corbett et al. [2] estimated that shipping-related particulate matter (PM) emissions are responsible for approximately 60,000 cardiopulmonary and lung cancer deaths annually, with most deaths occurring near coastlines in Europe, East Asia, and South Asia. The main pollutants emitted by ships are SO_2, because of the high sulfur content of marine bunkers, also PM and CO are emitted as a result of incomplete combustion of the low quality marine fuels and finally NOx that are emitted due to the high temperatures and pressures inside internal combustion engines. Additionally, as in every hydrocarbon's combustion process, CO_2 is emitted, which is not toxic at current levels; however it is the main greenhouse gas and contributes to global warming. Gaseous oxides of sulfur produced during combustion of fossil fuels can be oxidized to particulate sulfates SO_4^{2-}. In addition particulate emissions from shipping include OM (organic matter) and BC (black carbon) [3].

Global and regional organizations have recently adopted regulations to reduce pollutant emissions from ships in ports and coastal areas. There are no explicit PM emission limits; however the reduction of sulfur in marine fuels results in reduction of PM emissions. According to Annex VI of Marpol 73/78, the sulfur content of marine fuel in SECAs (Sulfur Emission Control Areas) should be less than 1% by mass (m/m) by the end of 2014 and 0.1% (m/m) thereafter. General sulfur limits in other sea areas are 3.5% (m/m) and will be reduced to 0.5% (m/m) by 1st January 2020 [4]. This will happen in case that the refinery industries can meet the demand of low sulfur fuel; otherwise the reduction will be

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postponed to 2025. Recently (1st January 2013), IMO took some measures to reduce the CO_2 by ships introducing mandatory EEDI (Energy Efficiency Design Index) for new ships and SEEMP (Ship Energy Efficiency Management Plan) for all ships [5].

The European Union issued the Directive 2005/33/EC [6] that came into force on 1st January 2010, which requires the sulfur content of the marine fuels to be less than 0.1% (m/m) when the ships are docked. The directive does not apply to ships in port for less than 2 hours and to ships, which switch off all engines and use shore-side electricity while at berth in ports. Shore side electricity or cold ironing addresses air pollution and noise by the ships at berth by providing the electrical power for the onboard auxiliary generators from the national grid. The provisions of the directive 2005/33/EC, though not mandatory for cold ironing, are considered as key forces for its adoption [7]. Additionally, with the recommendation 2006/339/EC [8], the European Commission advises that the Member States should consider the installation of shore-side electricity; particularly in ports where air quality limit values are exceeded or where public concern is expressed about high levels of noise, and especially in berths situated near residential areas. A supporting policy is the Directive 2003/96/EC that covers the taxation of energy products and electricity and allows member states to introduce exemptions or reductions of electricity taxation for specific policy considerations (Article 19) [9]. Sweden and Germany have already obtained the necessary authorizations to implement reduced tax rates on electricity provided to vessels at berth in ports as an incentive for the widespread adoption of shore-side electricity [10].

Apart from the global or regional regulations, the ports themselves are seeking policy initiatives (infrastructure, regulations, and incentives) to reduce emissions [11]. These include the subsidization of the use of LNG (Liquefied Natural Gas) by ships, the investment on LNG facilities, cleaner trucks, and lower tariffs for ships that reduce their speed close to port and shore side electricity [11].

The induced emissions from berthing ships that use shore side electricity depend on the energy mixture that the port relies on and this varies regionally and internationally [12] but reductions can be realized in most cases [13]. Zis et al. [12] found that provision of shore side electricity for all berthing vessels can reduce in-port emissions by 48–70%, 3–60%, 40–60% and 57–70% for CO_2, SO_2, NOx and BC, respectively. Increased benefits are observed for non-SECA ports with longer berth durations and a larger proportion of bigger ships. Jonge et al. [14] used the average emission factors for electricity generation in Europe and the emission factors for auxiliary engines of the ships that use 2.7% sulfur residual oil and estimated emission reductions of 94% (for Volatile Organic Compounds-VOCs), 96% (for SO_2 and PM) and 97% for NOx for shore side electricity compared to residual oil. The respective reductions when the ships used 0.1% sulfur Marine Distillate (MD) were 94% (for VOCs), 89% (for PM) 0% for SO_2 and 97% for NOx. The previous results show that shore side electricity and low sulfur marine oil are equivalent measures for the reduction of SO_2. However, shore side electricity has the great advantage of the simultaneous reduction of all air pollutants emitted by shipping at ports. It therefore merits particular consideration in ports where ship NOx and PM emissions are contributing to local air quality problems, such as exceedances of ambient air quality limit values for ozone and particles [8].

More than 20 ports, mainly in Europe and North America have employed shore-side electricity [7]. The port of Los Angeles subsidizes the necessary equipment for shore-side electricity of the first ship of each ship owner with 800,000$ and as a result 52 new built vessels were equipped [7].

Greece's domestic short sea shipping links the numerous islands of the Greek archipelagos with each other and with the mainland. It is used by 20 million passengers per year and it is vital for the welfare of the islands. Overall, there are 1500 daily links calling into 40 continental ports and 100 island ports [15]. Lesvos is the third biggest (in terms of area) island of the Greek archipelagos. Its economy is mainly based on agriculture and stock breeding with high quality products such as olive oil, cheese and ouzo. Lesvos has a unique culture, tradition and natural environment so it has a great potential to develop sustainable tourism based on its natural and cultural heritage [16].

The economy of Lesvos Island relies greatly on ships for the transportation of both passengers and freight. However, passengers can travel by airplane whereas all kinds of goods and products such as food, oil and other materials can only be transported by sea from the mainland. Therefore shipping and the port are crucial for the welfare of the island. Lesvos has a good ship connection with Chios and Piraeus (almost daily itineraries) and a sparse connection with Northern Greece (mainly Kavala). The vessels are mainly Ro–Ro passenger ships (with gross tonnage between 8000 and 17,000 t) that serve both passengers and trucks. There are also cruise ships, oil tankers, Ro–Ro Cargo ships and cargo ships. Overall, during 2012, there were 2617 vessel calls at the port of Mytilene. A new important trend is that in the last 5 years the movement of passenger ships from Turkey has greatly increased. In 2012, there were 762 passenger ships's calls to Mytilene's port from Turkey (Ayvalik and Dikili) with more than 50,000 passengers.

In the municipality of the capital Mytilene, with a population of 37,881 inhabitants [17], the port is located within the city limits (Fig. 1). In earlier studies, it was found that in Mytilene air pollution connected with the port does not last long and is related to the entry and departure of the ships to/from the port [18]. However, due to their concentrated nature, these episodes could create discomfort to residents and tourists, especially those living around the port. Measures to reduce the negative effects of the port (and transport in general) will strengthen the green nature of the island making it more attractive to permanent residents and tourists.

Regarding electricity production, the Greek islands are not connected to the mainland for their electricity needs and have low penetration of renewable energy. The electricity generation infrastructure of Lesvos Island comprises of one diesel power plant and two wind farms. The power plant consists of 10 electric generating sets with total installed power of 66,464 kW that mainly use heavy fuel oil. It is quite old since it first came into operation during the late 1970s, although the diesel engines have been replaced by new ones throughout the years as the energy demand increased [19]. There is no pollution abatement system at the power plant. The two wind farms have a total installed power of 11 MW [19].

The aim of this study is to estimate the quantities of particulate matter (PM_{10}) and CO_2 emitted by the ships at the port of Mytilene and to discuss the potential of shore side electricity to reduce the emissions utilizing power from the grid or renewable energy sources.

The structure of the paper is as follows: Firstly the emissions of PM and CO_2 by ships at the port of Mytilene (at berth or during maneuvering) are estimated for a peak time period (10–20 August 2012). The potential for the abatement of the emissions by connecting the auxiliary engines of the ships to the average national grid in Europe or to the existing electricity grid of the island is discussed. Then, simulations have been made for the required photovoltaic and wind turbine capacity to cover the needs of the auxiliary engines of the ships and the corresponding reduction in the emissions of pollutants. Finally conclusions and recommendations are presented.