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Pregledni članak
Review article

UDK / *UDC*: 347.795(094.2)
504.3.054

Primljeno / *Received:*
3. ožujka 2011. / *3rd March 2011*
Odobreno / *Accepted:*
24. ožujka 2011. / *24th March 2011*

AIR POLLUTION FROM MARITIME TRANSPORT – THE PROBLEM OF TODAY, THE CHALLENGE OF TOMMOROW

ONEČIŠĆENJE ZRAKA U POMORSKOM PRIJEVOZU – PROBLEM DANAŠNJICE, IZAZOV BUDUĆNOSTI

SUMMARY

There are almost 100,000 ships of various purposes, sizes, ages, energy efficiency etc. travelling around the world every single day. Although the maritime transport is considered to be environmentally friendly in comparison to other modes of transportation, all these ships produce some pollution, as in the majority of cases, they burn low grade bunker fuel that contains up to several thousands times the amount of sulphur compared to diesel fuel used in automobiles.
International legislation regarding the reduction of SO_2 and NO_X emissions from shipping is prepared and its enforcement has started. Nevertheless, IMO is severely criticized for setting too high limits for sulphur content in bunker. In addition, the ships' emissions in international waters still remain one of the least regulated areas.
MARPOL Annex VI and its revision have set the new limits for fuel sulphur content and NO_X. However the shipping industry is still not taking part of the emissions trading schemes, although the share of its emissions is growing rapidly (due to the growth in the seaborne trade as well as because of reductions of emissions in land transportation). There are several technological, operational and economic solutions that, if or when applied, should reduce the air pollution from ships.

Key words**:** *maritime transport, environment, air pollution, external costs, operational costs, fuel costs, fuel quality.*

SAŽETAK

Gotovo 100.000 brodova različite namjene, veličine, godine izgradnje, snage, itd. plovi svakodnevno po cijelom svijetu. Iako se pomorski prijevoz, u usporedbi s ostalim načinima prijevoza, blagonaklono odnosi prema okolišu, svi ti brodovi na neki način prouzrokuju onečišćenje budući da koriste pogonsko gorivo loše kvalitete koje sadrži i do nekoliko tisuća puta više sumpora u usporedbi s dizelskim gorivom kojim se koriste automobili.
Međunarodne zakonske odredbe koje se odnose na smanjenje emisija SO_2 i NO_x s brodova su donesene i njihovo je provođenje započelo. Usprkos tome, IMO je doživio veliku kritiku jer je postavio previsoku granicu za postotak sumpora u gorivu koje se koristi za pogon brodova. Uz to, emisije SO_2 i NO_x s brodova u međunarodnim vodama još uvijek ostaju jedno od područja koje je najmanje regulirano propisima.
U Aneksu VI. Marpol konvencije kao i u reviziji istih određene su nove granice sadržaja sumpora i NO_x u gorivu za brodove. Međutim, pomorski prijevozi još uvijek nisu uključeni u shemu tih emisija, iako njihov udio u tim emisijama sve više raste (zbog povećanog pomorskog prijevoza kao i zbog smanjivanja tih emisija u kopnenom prijevozu). Postoji nekoloko tehnoloških, operativnih i ekonomskih rješenja koja bi trebala, ako i kada se budu primjenjivala, smanjiti onečišćenje zraka s brodova.

Ključne riječi: *pomorski prijevoz, okoliš, onečišćenje zraka, vanjski troškovi, pogonski troškovi, troškovi goriva, kvaliteta goriva.*

1. INTRODUCTION

The world as we know it today would not be possible without transportation. We use benefits of transportation on daily basis as each transportation modes has plenty of positive economical and social impacts. However, all of them have also some negative impacts, which are demonstrated as various types of problems, like air quality deterioration followed by climate changes, accidents, congestions, medical issues etc. In the last decades these negative impacts are coming to the fore, thus the demand for their reduction is growing.

Maritime transport is not an exception, although it is still considered to be the transportation mode that is producing the least of these negative impacts, while at the same providing cheap and efficient transportation that as such stimulates production and international trade. However, the growth of seaborne trade causes the rise of negative impacts, making maritime shipping a subject of many debates.

The negative impacts of maritime transport are in range from waste dumping, non-indigenous organisms' diffusion and oil spills to the harmful atmospheric emissions. Heavy oil burned in ships' bunkers contains a high level of sulphur, thus producing large amounts of sulphur oxides (SO_X), nitrogen oxides (NO_X), carbon dioxide (CO_2), particulate matters (PM), volatile organic compounds (VOCs) etc. The amount of emissions depends on the vessel's type and age, as well as on the sailing region, wind and other meteorological conditions. In worst cases ship's emissions can be transported thousands of kilometres inland, extending over wide areas while affecting nature, human health and built structures.

Maritime transport is mainly an international business, thus the global agreement addressing this problem is needed. So far, the most of work has been done by the International Maritime Organization (IMO), and within it the Marine Environment Protection Committee (MPEC). However, ships' emissions in international waters still remain one of the least regulated segments of the global transportation system.

2. THE EXTENT OF THE PROBLEM

2.1. Regulatory framework

Environmental concerns arising from maritime transport have been intensified in recent year. In November 2003, the IMO adopted resolution A.963(23) on IMO Policies and practices related to the reduction of green house gasses (GHG) emissions from ships. With respect to GHG, substantial efforts are being taken to develop technical, operational and financial measures to regulate GHGs, in particular CO_2, emissions from shipping, but no mandatory instruments have yet been developed. GHG emissions from international shipping and the combustion of ship bunkers have so far been excluded from the international regulatory instruments dealing with climate changes, that is from the Kyoto Protocol. In March 2010 the IMO agreed to establish an expert group to prepare a feasibility study on market-based instruments to cut GHG emissions from ships [1].

The legislation governing the reduction of SO_X and NO_X emissions, resulting from the combustion of heavy fuel oils is being enforced. This is a subject of MARPOL Annex VI "Regulations for the Prevention of Air Pollution from Ships"[1] that was adopted in 1997 and came into force on 29th May 2005. Since that day, the MARPOL Annex VI imposes a global cap of 4.5% sulphur content in bunkers and a much more rigorous limit of 1.5% in Sulphur emissions controlled areas (SECAs). These requirements affect all ships above 400 gross tons (GT).

The highest sulphur content allowed in ship fuel will reduce globally; starting from 1st January 2012 the new limit will be 3.5% and starting from 1st January 2020 the new limit will be 0.5%. The allowed sulphur content in SECA will be 1.0% starting from 1st July 2010 and 0.1% starting from 1st January 2015.

In October 2008, the revised Annex VI of MARPOL and the revised NO_X Technical Code were approved. The new revision significantly tightens the NO_X and sulphur limits compared

[1] IMO ship pollution rules are contained in the "International Convention on the Prevention of Pollution from Ships", known as MARPOL 73/78. On 27 September 1997, the MARPOL Convention has been amended by the "1997 Protocol", which includes Annex VI titled "Regulations for the Prevention of Air Pollution from Ships".

Table 1 Emission factors for a slow speed diesel engine burning fuel oil
Tablica 1. *Faktori ispuštanja onečišćivača kod sporohodnih diesel motora koji koriste naftu kao gorivo*

Pollutant / *Onečišćivač*	**kg/ton of fuel** ***kg/t goriva***
Nitrogen oxides (NO_X) *Natrij oksid*	87
Carbon dioxide (CO_2) *Ugljični dioksid*	3.17
Sulphur dioxide (SO_2) *Sumpor dioksid*	2.0 × %S
Primary particulate matter (PM) *Primarne krute čestice*	7.6

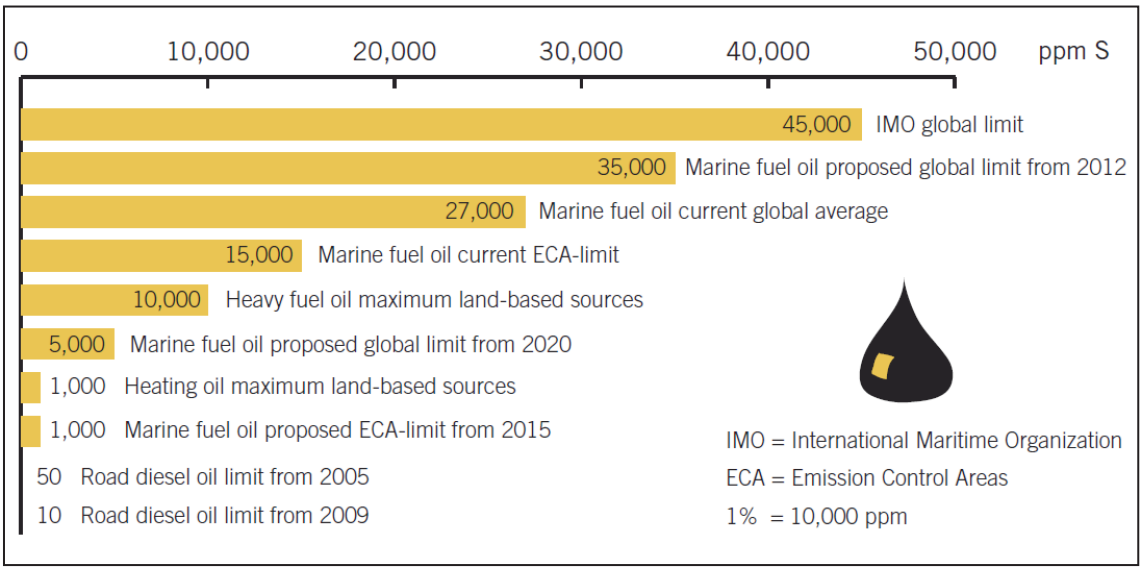
Source / *Izvor*: [4]

to the previous annex, and also includes requirements governing NO_X emissions from ships constructed from 1st January 1990 to 1st January 2000.

2.2. Assessment of current situation

According to the Lloyd's Register of Shipping there were almost 100,000 ships sailing in 2008. Maritime transport has contributed largely to the economic growth and prosperity all over the history, and is now considered as indispensable gear of international trade. In the year 2008 approximately 8.17 billion tons of cargo [2] have been carried out by roughly 53,000 of cargo ships [3]. And these numbers are constantly growing. It is thus clear how important maritime shipping is for a life as we know it today.

The vast majority of ocean-going ships utilize slow speed diesel engines that consume heavy fuel oils (HFO), which has high sulphur content. This oil is produced from residues from various refinery processes. Basically this means, that the heavy fuel oil is a waste, something that is left over after the crude oil refining process. Engines burning such fuel are very efficient, but at the same time have the worst emission factors among various types of ship engines (e.g. medium speed diesel engine or steam turbine).



Graphicon 1 The comparison among fuel types used in shipping and on land-based activities
Grafikon 1. *Usporedba vrsta goriva koja se koriste u pomorstvu i u aktivnostima na kopnu*

Source / *Izvor*: [5]

The emission factors of main pollutants of a slow speed diesel engine burning heavy fuel oil can be seen in Table 1.

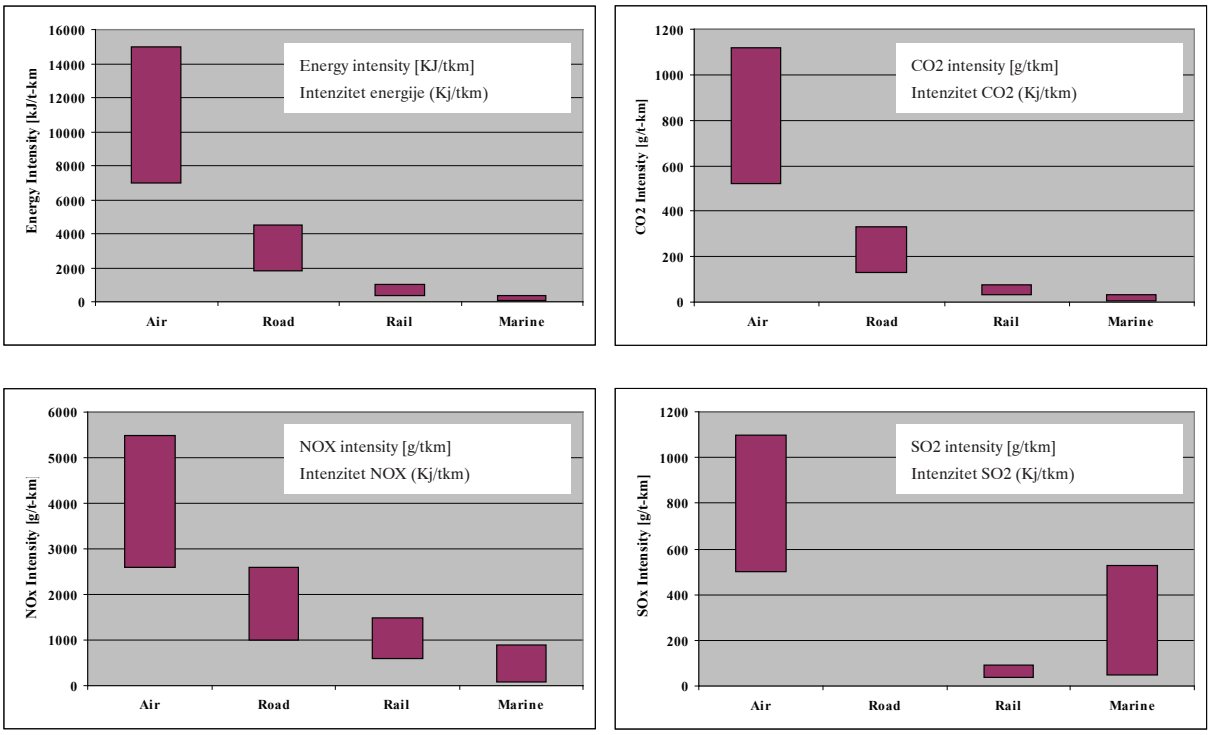
All together the ships burned 369 million tons of marine fuel in 2006 [5], 77% of which was heavy fuel oil [6]. In 2004, less than 6% of worldwide deliveries were equal to or less than 1.5% in fuel sulphur content. Almost 90% of worldwide deliveries contained 2% sulphur or higher, and approximately 44% of all deliveries were 3% or higher [7]. The latest figures from IMO show that over a 3 year rolling period between 2003 and 2005 the average sulphur contents of all fuels sampled was 2.7% with only 0.3% over the 4.5% limit [8].

The following charts show, why maritime shipping is still considered to be the most environmentally friendly mode of transportation and what is the main problem of maritime transport.

However, the combustion of maritime fuel in one single year produced an astonishing 16.5 million tons of SO_2, 24.3 million tons of NO_X, 1,9 million tons of $PM_{2,5}$ and over 1 billion tons of CO_2 [10]. For sure these amounts of emissions are not negligible. CO_2 emissions from maritime transport represent 1.5 – 3% of global emissions [11], but more stunning is the information that just 16 of the world's largest ships can produce as much lung-clogging sulphur pollution as all the world's cars [12]. It is obvious that IMO's rules on sulphur content in maritime fuel are still too loose, as the largest ships can each emit as much as 5,000 tons of sulphur in a year – the same as 50 million of typical cars, each emitting an average of 100 grams of sulphur a year [12].

Anyways things are improving with small steps; the 'Second IMO GHG Study 2009' study estimated that the 1.5% sulphur limit in force in the Baltic Sea and North Sea SECAs led to a 42% reduction in SO_2. Globally, that equated to a 3.4% reduction in SO_2 from shipping compared to the hypothetical unregulated scenario without any SECA sulphur limits in place [13].

Some of these pollutants, that is PM, NO_X and SO_2, have local or regional impacts on air



Graphicon 2 Comparison among modes of transportation; a) Energy intensity [KJ/tkm], b) CO_2 intensity [g/tkm], c) NO_X intensity [g/tkm], d) SO_2 intensity [g/tkm]

Grafikon 2. *Usporedba načina prevoženja a) Intenzitet energije (Kj/tkm); b) Intenzitet CO_2 (Kj/tkm); c) Intenzitet NO_X (Kj/tkm); d) Intenzitet SO_2 (Kj/tkm)*

Source / **Izvor:** [9]

quality. As such, they impact the human health (e.g. asthma, bronchitis and heart failure etc.), natural environment (e.g. soil and water acidification, damaged to plants etc.) and man-made buildings (e.g. corrosion). The study of James J. Corbett and others shows that that shipping-related PM emissions are responsible for approximately 60,000 cardiopulmonary and lung cancer deaths worldwide annually, with most deaths occurring near coastlines in Europe, East Asia and South Asia. Under current regulation and with the expected growth in shipping activity, they estimated that annual mortalities could increase by 40% by 2012 [14].

On the other hand, the emissions of GHG, like CO_2, have a global impact on climate. Climate changes that we are already witnessing are considered to be one of the greatest environmental, social and economic threats. Climate changes are demonstrated as global temperature increase, ice melting, sea level raise, devastating weather disasters etc. that are consequently transforming life on Erath.

The above emissions have caused a chain of reactions, both on local or regional level, as well as globally, and is thus very difficult to express their impacts in terms of money. Anyhow an estimation of marginal external costs of emissions from maritime transport is done for several world regions, as can be seen in Table 2.

By using average estimations for different pollutants, we can assume, that the external costs of maritime transport are about 240 billion € per year. Nota bene that this calculation does not include the costs of CO_2 emissions, neither some others, like for example VOCs or carbon monoxide (CO).

Table 2 Marginal external costs of emissions from maritime transport for countries surrounding sea areas (€/ton; year 2000 prices, May 2010 prices)
Tablica 2. *Marginalni troškovi ispuštanja kod pomorskog prijevoza za zemlje morskog okruženja (€/t; cijena za 2000., cijena za svibanj 2010.)*

	Eastern Atlantic *Istočni Atlantik*	Baltic Sea *Baltičko more*	English Channel *Kanal La Manche*	Northern *Mediterranean Sjeverni Mediteran*	North Sea *Sjeverno more*	Average *Prosjek*
SO_2						
2000	4,500	1,600	5,900	4,700	4,300	4,200
May / *svibanj 2010**	5,643	2,006	7,398	5,893	5,392	5,266
May / *svibanj 2010**	5,816	2,068	7,626	6,075	5,558	5,429
NO_X						
2000	4,800	2,100	5,400	6,200	3,100	4,320
May / *svibanj 2010**	6,019	2,633	6,771	7,774	3,887	5,417
May / *svibanj 2010**	6,204	2,714	6,980	8,014	4,007	5,584
NO_X						
2000	9,100	2,500	12,000	10,000	9,600	8,640
May / *svibanj 2010**	11,411	3,135	15,047	12,539	12,037	10,834
May / *svibanj 2010**	11,762	3,231	15,510	12,925	12,408	11,167

Source: Authors, based on data from [12], and re-calculated by using [15]
Izvor: *Autori, temeljeno na podacima iz [12], i preračunati pomoću [15]*

Note: ** base prices set in January 2000, ** base prices set in December 2000*
Napomena: * bazne cijene iz siječnja 2000., ** bazne cijene za prosinac 2000.

3. THE FUTURE

3.1. Estimation of future trends

The future does not look particularly bright when assessing the maritime transport emissons. IMO estimates that GHG emissions from maritime transport could increase by 150 – 250 % by the year 2050 in line with the expected growth in international seaborne trade [1].

The Japanese Shipowners Association produced three scenarios of future development of maritime transport emissions [16]:

High growth scenario; balance of fossil/non-fossil energy, 3.3% growth rate of seaborne trade, no improvements in shipping efficiency: CO_2 emission would be 1.3 billion tons in 2020 and 4.8 billion tons in 2050.

Regional integration scenario; 2.1% growth rate of seaborne trade, no improvements in shipping efficiency: CO_2 emission would be 1.1 billion tons in 2020 and 3.0 billion tons in 2050.

Efficiency improvements for new ships, 15% speed reduction for container ships and a 10% speed reduction for other ships: CO_2 emissions could be reduced by about 50%.

Once that maritime shipping enters the emissions trading schemes, the shipping industry would be obliged to purchase emission credits from other sectors in the case of the first two scenarios, as it would surpass the capping proposed for the years 2020 and 2050.

3.2. Technical solutions

According to the data collected by Lloyd Shipping Economist, approximately 3.000 cargo ships are on order. These ships should be built in accordance to the latest technological findings and ecological standards, which should result in lowered fuel consumption and consequently lowered global air pollution. These technological solutions are for example improved hull design, propulsion and ship engine technologies, usage of alternative energy sources (like liquefied natural gas (LNG) or even wind), sophisticated computer technology etc. The overall potential CO_2 emission reductions from current vessel design strategies for newbuilds can be estimated to be in the range of 5-30% [17].

However, also the existing ships can improve their environmental and economic performance by applying some activities, like for example hull and propeller cleaning, better main and auxiliary engine maintenance and tuning, optimized trimming and ballasting etc. Technical retrofit and maintenance strategies on existing vessels can potentially reduce CO_2 emissions from the existing fleet by 4-20% [17].

3.3. Operational solutions

The simplest way to achieve less emissions is by cutting down the navigation speed, at least when this is possible. IMO has calculated that a speed reduction of just 10% across the global fleet by 2010 would result in over a 23% reduction in emissions [18]. On a single ship case this is proved in Table 3 with the example of a small container ship with the deadweight of 32,153 tons and a capacity of 2,628 TEU. One can see (see Table 3), that an average size ship, like the one from the example, can produce more that 100,000 € of external costs per day.

For a merchant ship, especially in tramp market, the navigation speed is determined by the market situation. However, liner ships too, like the one from the example, can adjust their speeds according to the market situation, neglecting completely the emissions that they produce when increasing the speed. Some studies show that operating containerships at slower speed both reduces fuel costs and GHG emissions, even allowing for the need to deploy an extra ship to maintain sailing frequencies [19]. Of course in this case, the ship-owner will have to put into the calculation the fixed costs (operational costs plus the depreciation) as well as the fuel costs and all other voyage costs to find out the appropriate speed, leaving out the costs of emissions. However, if in the future shipping industry will be included in emissions trading schemes, then the calculation of an optimal speed in consideration to emissions costs will be mandatory and the optimal navigation speed will be somewhat different.

4. CONCLUSIONS

The current limits for sulphur content in marine bunker fuel are a way too high to globally produce considerable benefits in regards to maritime transport emissions. As the emissions from maritime transport generally continue to

Table 3 Calculation of daily emissions and emission costs at different navigation speeds
Tablica 3. *Izračun dnevnih ispuštanja plinova i njihovi troškovi kod različitih brzina plovidbe*

Speed / *Brzina*	Speed reduction/ *Smanjenje brzine*	Consumption [t/day]/ *Potrošnja* [t/dan]	Consumption reduction/ *Smanjenje potrošnje*	Co_2 emiss. [t/day]/ *Ispuštanje* Co_2 [t/dan]	So_2 emiss. [t/day] at S=2.7% / *Ispuštanje* So_2 *kod* S=2.7%	So_2 emiss. [t/day]at S=1.5% (LSF) / *Ispuštanje* So_2*kod* S=1.5% (LSF)	NO_X emiss. [t/day] / *Ispuštanje* NO_X[t/dan]	Costs / *Trošak* (CO_2) [€]	Cost / *Trošak* (SO_2) [€]	Cost / *Trošak* (SO_2) LSF [€]	Costs / *Trošak* (NO_X) [€]	Total emission costs / *Ukupan trošak ispuštanja* [€]*	Total emission costs / *Ukupan trošak ispuštanja* (LSF) [€]*
6	72.7%	3.4	97.2%	10.8	0.184	0,967	0.296	216	997	554	3,303	4,516	4,073
8	63.6%	6.7	94.4%	21.2	0.362	1,429	0.583	425	1,964	1,091	6,509	8,898	8,025
10	54.5$	12.1	89.9%	38.4	0.653	2,065	1.053	767	3,547	1,971	11,756	16,590	14,493
12	45.4%	20.3	83.1%	64.4	1.096	2,886	1.766	1,287	5,951	3,306	19,722	29,960	24,315
14	36.4%	31.7	73.6%	100.5	1.712	3,863	2.758	2,010	9,293	5,163	30,797	42,100	37,970
16	27.3%	47	60.8%	149.0	2.538	5,012	4.089	2,980	13,779	7,655	45,662	62,241	56,297
18	18.2%	66.6	44.5%	211.1	3.596	6,313	5.794	4,222	19,525	10,847	64,704	88,451	79,773
20	9.1%	91	24.2%	288.5	4.914	7,763	7.917	5,769	26,678	14,821	88,409	120,856	109,000
22	0%	120		380.4	6.480	9,307	10.440	7,608	35,180	19,544	116,583	159,371	143,736

Source: Authors, input data on speed and consumption are retrieved from Ports of Call
Izvor: *Autori, ulazni podaci o brzini i potrošnji uzeti iz luka pristajanja*

Note: *PM and some other substances, like VOC or CO are not included in the calculation. Calculations are based on coefficients from Table 1 and May 2010 **values from Table 2. The price of CO_2 emissions used in the calculation is 20€. LSF is low sulphur fuel (sulphur content is 1.5%), which produces less emissions and costs approximately 50$/ton more than regular IFO.

Napomena: **Primarne krute čestice (PM) i neke druge tvari, kao što su lako isparljive organske smjese (VOC) ili ugljični monoksid (CO), nisu uključeni u izračunu. Izračun se temelji na koeficijentima iz tablice 1 i na vrijednostima za svibanj 2010. **iz tablice 2. Cijena ispuštanja CO_2 koja je korištena u ovom izračunu iznosi 20 €. LSF označava gorivo s malim postotkom sumpora (sadržaj sumpora iznosi 1,5%), koje ispušta manju količinu plinova, a troškovi su približno 50$/t viši nego li kod običnog IFO.*

grow it is expected that in near future the regulations in this field will become much stricter.

Besides lower limits for sulphur content in the ships' fuel and the declaration of new SECAs, the probable outcome is also the inclusion of maritime transport into the emissions trading schemes. All of these will create obligations for shipowners, ship operators, charterers, flag states and port states controls. It is clear that this will impose huge impacts to the shipping sector and consequently to economies and communities as a whole.

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