# SHIPS, SULPHUR AND CLIMATE

Pre-print edition, for comments only

## - Is It a Good Time to Reduce the Sulphur Emissions from Shipping?

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# THE END OF BUNKER OIL?

The International Maritime Organization (IMO) decided, in October 2008, that the maximum allowable sulphur content in the fuel used by ships should be reduced to 0.5 per cent by 2020, and to 0.1 per cent in the more stringent Special Emission Control Areas, or SECAs. According to IMO, this is necessary, because sulphur emissions are harmful to human beings. Ship fuel presently contains on average 2.7 per cent of sulphur.

The enforcement of the treaty might add USD 200 billion to the shipping companies' annual fuel bills. This could be a major problem, because the International Framework Convention on Climate Change will, sooner or later, be expanded so that it will also force the ships to reduce their greenhouse gas emissions. The IMO treaty does not pay any attention to greenhouse gases. On the contrary, it will, in practise, force the ship-owners to spend a lot of money to cutting their sulphur emissions in a way that might actually increase the greenhouse gas emissions from shipping.

It will be very expensive to first invest in measures that cut the sulphur emissions in a way that increases the greenhouse gas emissions, and then make new investments to reduce the production of the greenhouse gases. Wouldn't it be more reasonable to find solutions, which would tackle both problems at the same time, with a realistic price tag? The accepted IMO treaty is so expensive, that it might in practise ensure, that most of the world's shipping companies will not be able to do much to reduce their greenhouse gas emissions during the next few decades.

Besides, the ships' sulphur emissions also cool the planet. They have a small direct cooling impact on the world's climate. Above all, they assist the formation of globe-cooling clouds over the oceans. According to the most often quoted estimate the enforcement of the IMO treaty might reduce the ships' cooling impact from 0.58 to 0.27 watts per square metre.

Measurements conducted by NASA, using satellites and other instruments, have estimated that global warming currently amounts to 0.85 watts per square metre (plus or minus 0.15 watts/m2). In other words the enforcement of the IMO treaty might not only make it more difficult to reduce the carbon dioxide emissions from the shipping sector, it might – even according to a relatively conservative estimate -- directly increase the global warming by 31 - 44 per cent (or even more, if the aerosols' cooling impact has been underestimated).

This could be very dangerous, especially because the heating impact of the IMO treaty would not be evenly distributed. Much of the impact would concentrate on the North Atlantic and on the Arctic Ocean. This is an important consideration, because the northern water and land areas contain vast stores of organic carbon and methane. According to many researchers, even slight additional warming might destabilize these deposits, so that huge amounts of greenhouse gases will be released into the atmosphere. Another vicious circle is created when snow and ice are replaced with open water, dark conifers or black soil. Snow and ice reflect most of the solar radiation straight back to space before it becomes converted to heat, but open water and black soil absorb sunlight like a sponge.

So, is this really such a good time to cut the ships' sulphur emissions, or should other policy alternatives be considered, before the final enforcement of the treaty? While the rest of the world is doing its utmost to prevent a global climate catastrophe, the International Maritime Organization seems to be doing its utmost to push the humanity over the edge.

In the following pages we will discuss the same issues in a little bit more detailed way. We will have a look on the scientists' efforts to quantify the cooling impact of the ships' present sulphur emissions, and explain why the withdrawal of the ships' particle parasol might – in the present situation – be more destructive than what has this far been acknowledged. We take a look at what is now happening at the Arctic Ocean, and why the heating of the North Atlantic and the Arctic Ocean could be the most serious part of our whole planetary overheating problem.

We briefly discuss the likely impacts of the IMO treaty on public health, on the acidification of the oceans, and on the shipping sector's greenhouse gas emissions. Finally, we present a number of alternative policy options, and discuss their merits and complexities.

We are very well aware, that it is not customary to re-negotiate international treaties almost immediately after they have been accepted by all the parties. However, sometimes something like that just needs to be done, because the alternative would be even more unthinkable.

**In Turku and Helsinki, August 2010**

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# THE GREAT AEROSOL DEBATE

According to measurements conducted by NASA, the Earth receives from the Sun a little bit more radiation that it sends back to space. This small imbalance, amounting to 0.85 watts per square metre, in the heat budget of our home planet is known as global warming, and might have profound importance for the future perspectives of mankind.

According to the present scientific understanding, the extra greenhouse gases produced by the humanity – above all carbon dioxide, methane, nitrous oxide, ozone and freons – now heat the planet by 2.8 watts/square metre. Besides this, black carbon (soot and tar) particles in the air and on top of snow and ice heat the planet by at least 0.44, and possibly by 0.9 watts per square metre. The white condensation trails left by the jet planes at the sky, and the artificial cirrus clouds that form from them, as well as from our hydrogen and methane emissions, also have a heating impact. These heating impacts, counted together, amount to approximately 4 watts for every square metre on our planet’s surface, or roughly 2,000,000 gigawatts for the whole globe.

So why is the Earth only heating up with the power of 0.85 watts per square metre, plus or minus 0.15 watts?

What comes to the radiative forcing caused by the various greenhouse gases, the margin of error is rather small. These effects can be measured, and their impact can easily be seen in the spectre of the solar radiation reaching the Earth's surface. Therefore, the most plausible explanation for the discrepancy is that we have underestimated the impact of the anthropogenic factors that do not heat up the planet but which influence the situation in the opposite way. The best candidate is the so called bright aerosols, tiny and highly reflective particles floating in the atmosphere.

We produce large amounts of shiny aerosols, that have a cooling impact on our planet, and which thus compensate part of the warming caused by the greenhouse gases, soot and man-made cirrus clouds. Such bright aerosols include ash and dust particles, nitrogen oxides, the hundreds of different organic compounds created when wood or other biomass is burned and, above all, sulphur. Bright particles radiate some sunlight directly back to space, but they also assist the formation of clouds, make the clouds more reflective and increase their life-span. These effects multiply the aerosols’ total cooling impact.

The Intergovernmental Panel on Climate Change (IPCC) has estimated, that such man-made aerosol emissions currently compensate approximately 1 watt per square metre of the global warming.

However, if the aerosols only cooled the planet with 1 watt/m2, the Earth should now be heating roughly four times more than seems to be the case.

Therefore, some scientists have remarked, that the real figure might be substantially higher, perhaps up to 3.5 watts per square metre. If this figure is closer to the mark, man-made aerosols actually cancel three quarters of the warming, instead of only one quarter of it.

More research is needed before we can say, with certainty, what is the truth about the matter. At the moment the main stream of scientists would probably support the older, lower and more conservative figures. But the stream of scientific thought arguing for the higher figures includes many of the most prominent scientists in the field, like Paul Crutzen, the only modern climate scientist who has won a Nobel Prize in science. This is notable, because Crutzen has often produced predictions that have been dead on the mark, even though they were originally opposed by a great majority of mainstream scientists.

Crutzen presented, in June 2003, new and important calculations about the subject in a workshop held in Dahlem, Germany. According to Crutzen's new assessment sulphur and other aerosols and the clouds produced by them might actually have cancelled at least one half and possibly three quarters of the warming.

In 2005 three prominent climate modellers, Meinrat Andreae, Chris Jones and Peter Cox, refined Crutzen's calculations. According to their assessment the amount of expected global warming by the year 2100 could increase from the official prediction of 1.5 - 4.5 degrees to 6 - 10 degrees, if the cooling impact of man-made aerosol emissions was removed at the same time.

Most mainstream climate scientists now admit that the cooling impact of aerosols is probably somewhere between one watt and three and a half watts per square metre.

Even the IPCC has now admitted, that the cooling impact of the aerosols might actually amount to almost three watts per square metre. It still uses the lower figure as a baseline, but it has equipped some of the columns in its graphs with additional bars representing the current scientific uncertainty (see Figure 1).

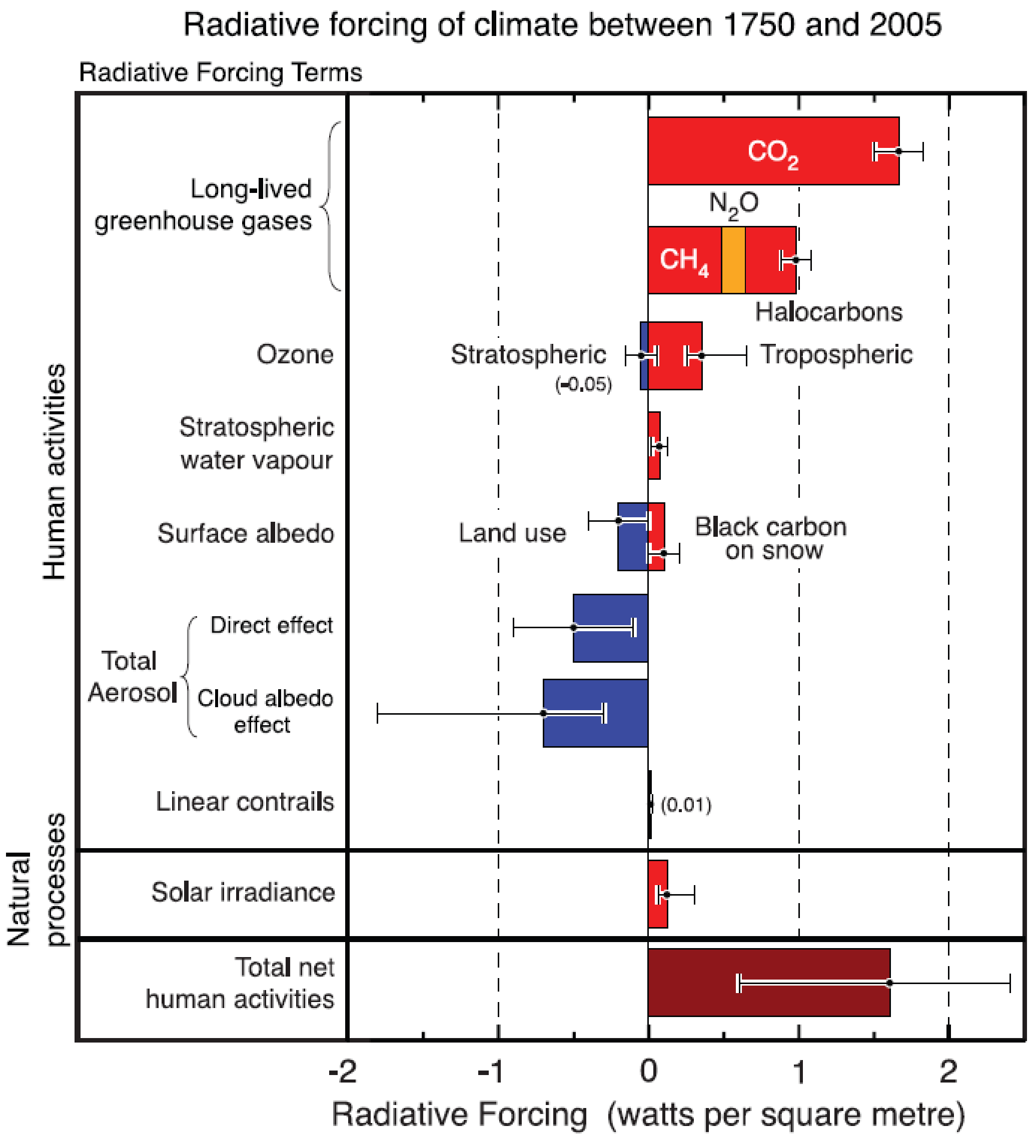

***Fig 1.*** *Radiative forcing is a factor that alters the planetary balance of incoming and outgoing energy. Red columns are positive radiative forcings, or factors that heat the planet. Blue columns are factors that cool the planet, or that produce a negative radiative forcing. The values in the figure refer to changes relative to preindustrial conditions, defined as conditions prevailing at 1750, and are expressed as watts per square meter. The thin bars (lines) extending some of the columns represent IPCC's interpretation about the extent of currently prevailing scientific uncertainty.*

# ASSESSING THE COOLING IMPACT OF SHIPPING

Ocean-going freight ships burn heavy fuel oil (bunker oil) that contains, as a global average, about 2.7 per cent sulphur. This is 15-20 per cent of the humanity's total sulphur emissions. Aerosol researchers have calculated, that the sulphur spread by the ships over the oceans provides between 17 and 39 per cent of total cooling impact of anthropogenic aerosol emissions.

Although the associated uncertainties are still high, model results indicate that this cooling impact far outweighs the warming effects from greenhouse gases (carbon dioxide, methane and ozone) and the dark soot particles from shipping.

The sulphur emitted by ships is the most important part of our "particle parasol" because some of our ships often spread their emissions over marine regions where there is otherwise very little air pollution or bioaerosols (particles produced by trees and other vegetation), and thus only a very limited number of cloud condensation nuclei. The sulphur from ships has a direct cooling impact, but it also assists cloud formation and increases the number of cloud droplets inside a cloud, thus making it whiter and more reflective. Ships often leave behind them massive but elongated cloud formations, known as ship tracks.

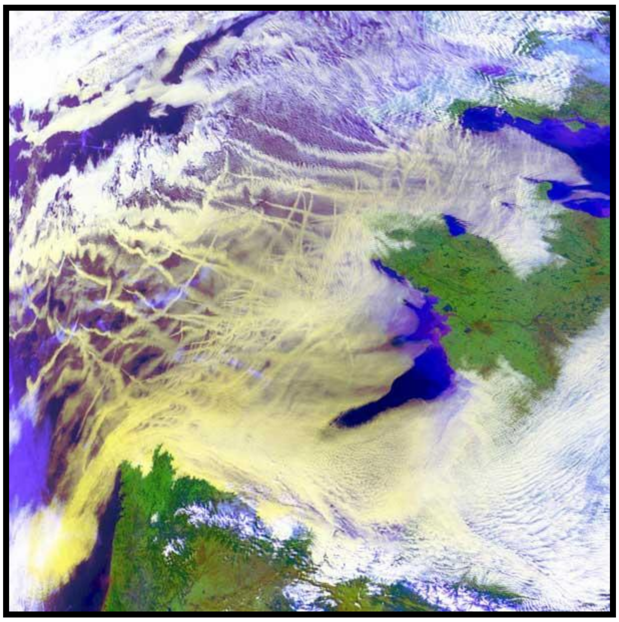

***Fig 2.*** *An extreme example of how emissions from vessels affect the cloud cover*

The British scientist Sean Twomey showed in the late 1970's that the reflectivity of a cloud is influenced by the average size of cloud droplets. Most clouds consist of minuscule droplets of water which have condensed on even tinier particles floating in the air, on the so called cloud condensation nuclei. If the water in the cloud is divided between a very large number of very small cloud droplets, the cloud is whiter and reflects sunlight better than if the average size of the cloud droplets is larger and there is a lesser number of them.

According to the Center for Atmospheric Research in Boulder, Colorado, the average size of the cloud droplets in the clouds over the oceans is 25 microns, while the average over land is only 7 microns. This means that the clouds over the continents are, on average, more reflective than the clouds over the oceans.

Ship emissions can increase the concentration of Cloud Condensation Nuclei to over 10 times the levels that typically prevail in the clean air over the Atlantic Ocean. Thus sulphur emissions from ships result in whiter clouds. Even a small change in the reflectivity of the clouds, hardly even visible to human eye, can have a significant climatic impact due to the vast areas covered by ship routes.

The ship's aerosol emissions have the most profound effect in pristine maritime conditions. The predominant area for ship track occurrence is the latitude band between 30 and 60 N in both the North Atlantic and the Pacific Ocean. In the Southern Hemisphere ship tracks are much less frequent and are concentrated between 10 and 30 S off the west coasts of southern Africa and Australia.

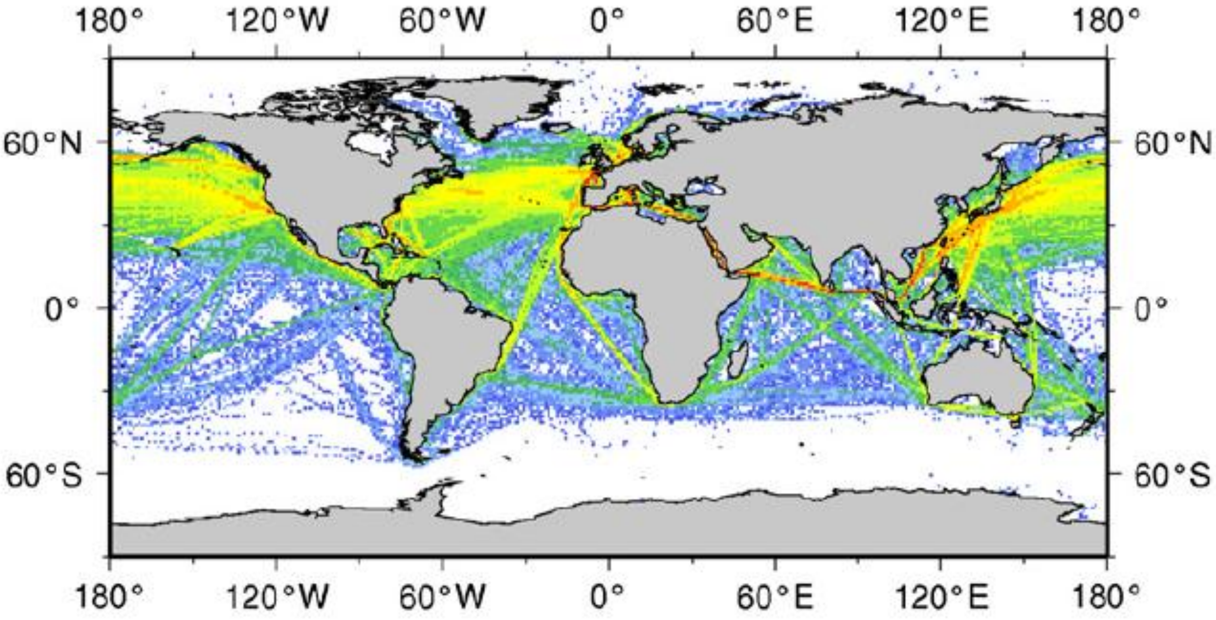

***Fig 3.*** *Distribution of shipping routes*

By reducing the average size of cloud droplets, sulphur might even increase the life-span of clouds. The smaller the droplets, the longer it should take before they can form raindrops and fall down as rain.

Land areas tend to be more reflective than ocean surface. Also for this reason aerosols produce a bigger change in albedo (reflectivity) over oceans than over land.

Of the anthropogenic sources of atmospheric aerosol emissions, shipstack effluents provide the clearest demonstration of the indirect aerosol effect on the cloud cover's reflectivity. Curves of larger reflectance in cloud fields (ship tracks) can be observed in satellite imagery as a recurrent phenomenon. All studies agree that the present-day net radiative forcing due to shipping is negative, which means that the ships are cooling the planet. Different studies give varying estimates of the amount of cooling due to shipping, but even according to the smallest estimates, the cooling impact of shipping is significant.

According to an often quoted calculation, by Ernst Lauer and his colleagues, the ships' cooling impact should be about 0.58 watt/m$^2$ in 2012 with no reductions in the sulphur content of their fuel. However, if the planned emission cuts were carried out already at that time (ahead of the real schedule), the cooling impact would be reduced to 0.27 watt/m$^2$. The difference, 0.31 watt/m$^2$, should increase our planetary heat balance, or global warming by 31 - 44 per cent.

However, this estimate is based on a relatively conservative estimate on the aerosols' overall cooling impact. The calculation also assumes, that almost one half of the loss of sulphur aerosols will be compensated by the increased production of nitrate aerosols, which can also act as cloud condensation nuclei.

What if the higher figures, proposed by Paul Crutzen and many other prominent scientists, are closer to the mark?

If the overall cooling impact of aerosols is 3 or possibly even 3.5 watts per square metre and the ships' contribution amounts to 40 per cent of this (1.2 to 1.4 watts per square metre), the planned sulphur emission cuts might actually more than double the rate of global warming.

The worst case scenario might become a reality, if the IMO Convention forces ships to move from bunker oil to liquefied natural gas (LNG), which would probably be the cheapest alternative.

In LNG ships sulphur emissions would not be cut to 0.5 per cent but to close to zero, and the nitrogen emissions would also be cut by 80 per cent because of the lower engine temperatures. Thus nitrate aerosols would not compensate the loss of sulphur in gas-powered ships. Also the greenhouse gas emissions might increase, due to a number of different factors (we come back to this issue in a separate chapter dealing with the ships' future fuel alternatives).

Above all, the impact of a sudden removal of the sulphur and cloud parasol provided by the ships would not be evenly distributed: it would concentrate over the heavily trafficked marine areas like the North Atlantic.  This means that the enforcement of the IMO treaty might accelerate the warming of the Arctic in a potentially catastrophic way.

# THE MELTING OF THE ARCTIC, OR WHY IT MIGHT NOT BE SUCH A GOOD IDEA TO HEAT THE NORTH ATLANTIC, RIGHT NOW

A little bit more than fifty years ago, on 3rd August, 1958, US Nautilus became the first submarine to reach the North Pole. The captain of Nautilus, commander William R. Anderson, wrote a book about the journey, called “Nautilus 90 North”. Anderson wrote that according to the submarine’s sonar, Nautilus had been under surprisingly sturdy polar ice throughout the journey. The thickness of the ice had varied between two and a half and twenty-five metres. Here and there the keels of higher pressure ridges had penetrated to the depth of forty or fifty metres.

In 2006 the official prediction was that permanent ice cover would not disappear from the Arctic Ocean before 2070 or 2080, even if the climate were to continue to warm up in line with the predictions of the Intergovernmental Panel on Climate Change (IPCC). But in summer 2007 the National Ice and Snow Data Center (NISDC) of the USA announced, that the whole Arctic Ocean could become ice-free in 2020 during the height of the melting season, fifty or sixty years before the "official schedule".

The reason for this drastic revision was simple: the extent of the sea ice in the Arctic Ocean had diminished very rapidly in just a few years. In 2007 the extent of the area covered by marine ice was only half of what it had been in the 1950’s, and the remaining ice masses were much thinner than before.

During 2008 the extent of the Arctic marine ice did not shrink further, because the summer was cool and the skies cloudy. But in spite of this, the amount of thick multi-year ice in the Arctic Ocean at the end of September 2008 was only half of what it had been a year earlier. The average thickness of the ice pack was probably somewhere between a metre and two metres, in stark contrast to the situation in August 1958. Many scientists now predicted, that the Arctic Ocean might lose the rest of its multi-year marine ice and become totally ice-free at the end of the summer by 2012 or 2013.

September 2009 a team of Canadian researchers, led by David Barber, no longer found any multi-year ice during their voyage over the Arctic Ocean. They found none of it even at the Beaufort Sea, north of Canada's Arctic archipelago. The Canadian research team only found thin and fragile ice, with an average thickness of half a metre. Such a thin membrane of ice could vanish in a few weeks, during the next abnormally warm Arctic summer.

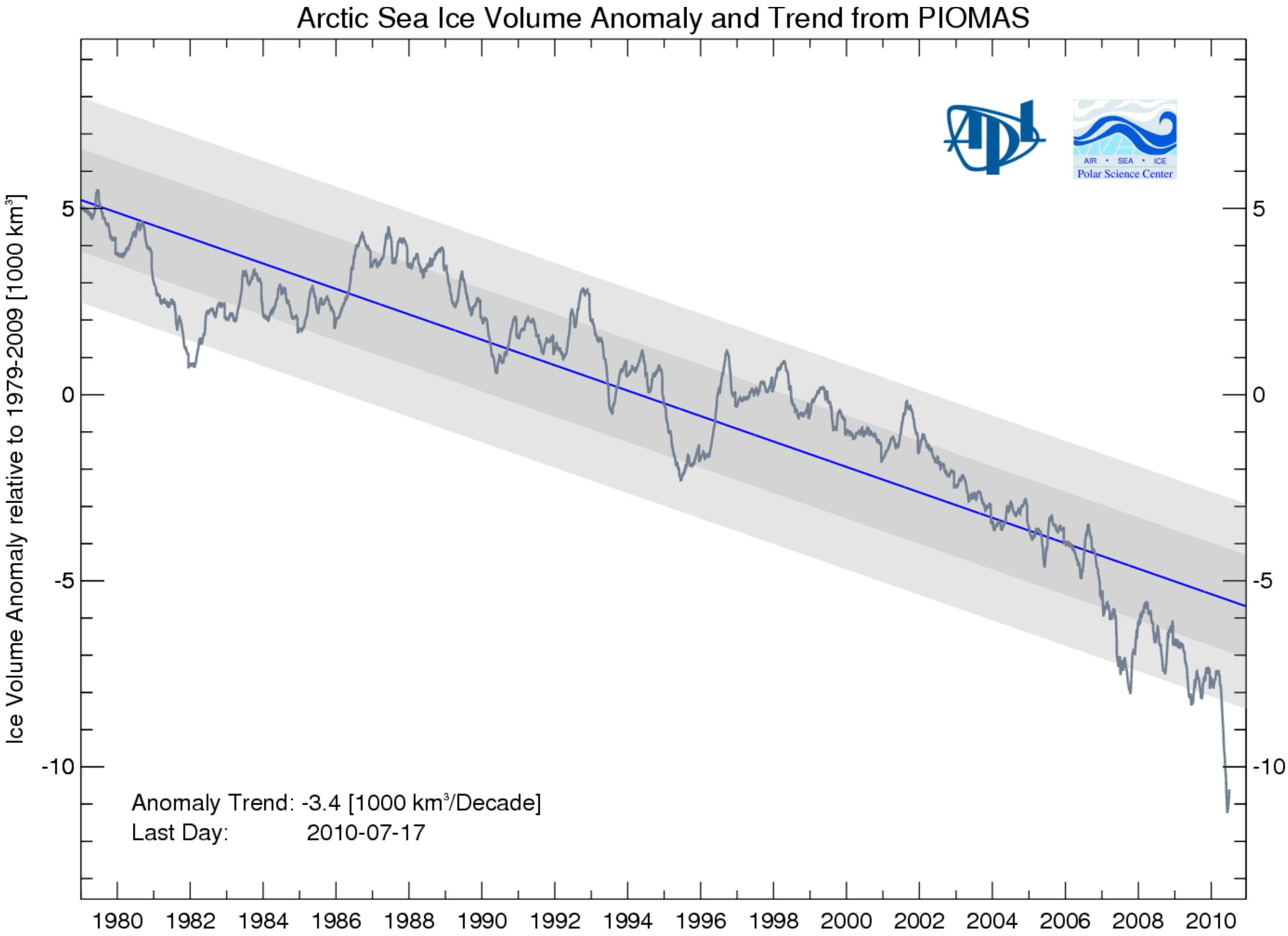

***Fig 4a**. Sea Ice Volume Anomaly Trend 1979-2010*

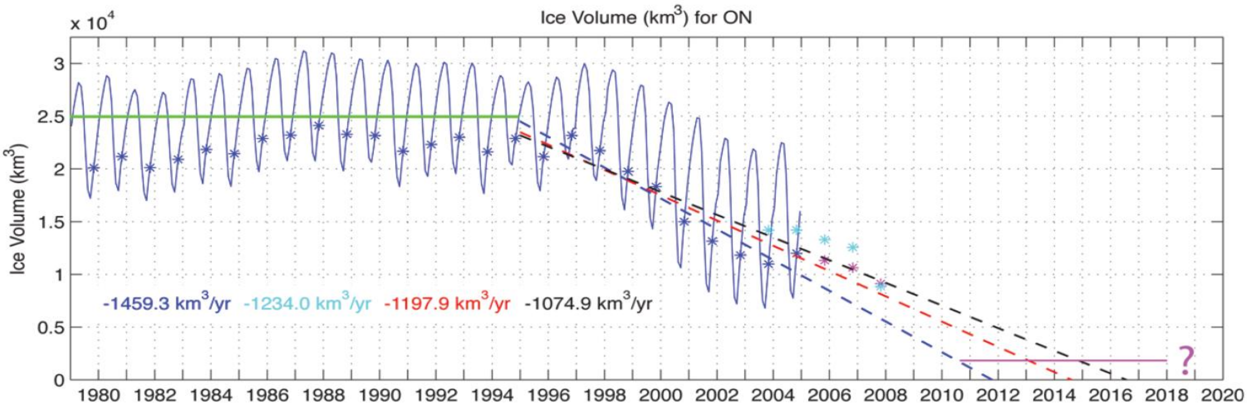

***Fig 4b**. Total projected ice volume*

According to satellite data there was some multi-year ice left, even though the amount had again been halved during a single melting season. However, the field observations contradicted the satellite data. It seemed that the half-melted ice landscape was producing forms whose radiometric and scattering characteristics were almost identical to those of multi-year ice, so that satellites could no longer see the difference.

In 1994 there had still been about 25,000 cubic kilometres of floating ice in the Arctic Ocean, if we take the annual average, including both the summer and winter months. At the moment the average could be somewhere between 2,500 and 5,000 cubic kilometres. In other words, we may have lost 80 per cent or more of the Arctic pack ice in sixteen years, and a much larger percentage since the year 1958.

This may have profound consequences for the climate of our planet, because snow and ice are very good at reflecting sunlight back to outer space. They typically have a reflectivity (an albedo) of 70 to 90 per cent. Fresh-fallen, pure-white snow can reflect 98 per cent of solar radiation straight back to space. This is an extreme case, but even melting snow and ice still have an albedo of 50–60 per cent.

Open water only reflects 4–10 per cent of the sunlight back, depending on the angle of the coming solar radiation. In other words, watery surfaces absorb 90–96 per cent of the solar energy falling on them.

The Indian-American climate scientist Veerabhadran Ramanathan, who was the first to measure the radiative forcings of the new greenhouse gases like freons, has calculated that a 3 percentage point reduction in the Earth's average reflectivity would heat the planet as much as a five-fold increase in the atmosphere's carbon dioxide content. The melting process now taking place in the world's polar regions might finally reduce the Earth's reflectivity by more than 3 percentage points. If Ramanathan's calculation is correct, these changes in the planet's reflectivity would be equivalent to adding three or four thousand billion tons of extra carbon into the atmosphere – a few centuries worth of carbon dioxide emissions.

During the early Eocene period, 55 million years ago, the Earth was perhaps 13 degrees Celsius warmer than now. The average temperature at the North Pole, however, was a staggering 43 degrees higher than at present, plus 20 Celsius instead of minus 23, largely because the region had lost its entire, effectively reflecting snow and ice cover.

During our own time, extreme heating of the Arctic would be even more dangerous than 55 million years ago. The present Arctic has literally thousands of millions of hectares of land and water areas with huge frozen or semi-frozen reservoirs of organic carbon and methane. Many of these greenhouse gas reservoirs have been frozen without interruption for a very long time, sometimes for more than a million years.

Northern forest soils and the vast northern peatland areas contain huge amounts of carbon, and new studies have estimated that there is at least 1,500 billion tons of carbon stored in the terrestrial permafrost areas. Most of this has been frozen into the so-called yedoma or wet permafrost. In yedoma areas most of the permafrost and its carbon become covered with water when the ground starts to melt. Therefore, most of the carbon in the permafrost is released as methane, and not as carbon dioxide. The difference is important, because as long as methane stays in the atmosphere, it is about one hundred times more effective as a greenhouse gas than carbon dioxide.

Methane's relative global warming potential becomes smaller if we posit calculations on a longer perspective, because it breaks down in the atmosphere relatively quickly (see the chapter about fuel alternatives for more details). In other words, large eruptions of methane are the more dangerous the faster they occur. This is a concern, because we are now heating the Arctic much faster than it could ever heat in any normal conditions. We are, at the same time, increasing the concentrations of greenhouse gases, adding more cirrus clouds on the sky and producing a lot of soot and dust that falls down on the Arctic ices.

There is more methane under the permafrost, in sediments known as methane clathrates or methane hydrates. In the clathrate deposits methane gas has been trapped inside small molecular-level cages of ordinary ice. The first methane clathrates were discovered by Russian scientists already in the 1960’s, but we still have only a vague idea of the size of these reserves. According to one regularly quoted estimate there could be at least 400 billion tons of methane in the clathrate stores beneath the terrestrial permafrost.

The methane clathrate deposits on the continental slopes are even larger. According to best current estimates they might contain about 10,000 billion tons of methane, part of this inside the ice and the rest in gas pockets under the ice. These formations may be the greatest threat to our future survival, because they are only stable under a high pressure and when the temperature of the surrounding water is close to the freezing point of water. Clathrates in the Arctic Ocean can exist much closer to the surface than in other oceans, because the water is very cold. Surface water in the Arctic Ocean always stays between minus two and zero degrees Celsius. The “warmest” water, more than 0.5 degrees Celsius, can be found at depths of 200–500 metres.

Furthermore, roughly one half of the bottom of the Arctic Ocean consists of submerged continental shelves, which are covered by permafrost. In other words there is many times more yedoma under the water than above the water. There are not even educated guesses on how much organic carbon these submarine permafrost areas might contain.

In summer 2008 Canadian, Swedish and Russian scientists reported, that on many sites large amounts of methane had started to bubble to the surface from submarine permafrost. The Swedes remarked, that practically all the methane seemed to be entering the atmosphere, raising the local concentrations of the gas by one hundred or, on some localities, by a thousand times. People living at Greenland’s western coast told British and Canadian researchers about “large explosions” in the sea, and about dead whales that had subsequently floated to the surface. It has not been possible to confirm these reports, but a breakdown of a clathrate bed would produce eruptions with a resemblance to depth charge ("water bomb") explosions.

In August 2009 a team of the University of Southampton discovered, around the Arctic archipelago known as Spitzbergen, 250 sites on which the submarine methane clathrate fields had started to melt and release methane. The melting clathrates were at depths of 150 -- 400 metres. All the methane was still dissolved into sea water as carbonic acid before it reached the surface, but this will change if much more methane will be released.

It is very important that we halt the thawing of the Arctic before all these stores of organic carbon and methane begin to erupt into the atmosphere, in a much larger scale.

# FUEL ALTERNATIVES FOR THE POST-BUNKER ERA AND THE SHIPS' GREENHOUSE GAS EMISSIONS

Shipping is responsible for approximately three per cent of all the manmade carbon dioxide emissions. Moreover, without aggressive emission reduction strategies, the carbon dioxide emissions from ships could double from the present-day values by 2050.

According to the optimistic view the shift from heavy sulphurous bunker fuel to LNG (liquefied natural gas) or to other clearner fuels could also contribute to reducing the ships' greenhouse gas emissions. It is, however, far from certain whether this overly optimistic assumption corresponds with the reality, or whether it is only wishful thinking. There are, in fact, strong reasons to assume that the exact opposite could be true.

## Cleaner oil and greenhouse gas emissions

If residual fuel is processed further to lighter low-sulphur shipping fuel, approximately 15 per cent of the original energy content of oil will be lost in the processing, before the fuel is even loaded into the ships' tanks. In the conventional refinery process that is used to produce bunker oil, the loss only amounts to about 7 per cent.

For this reason, deep conversion of bunker fuels will result in additional carbon dioxide emissions. The deep conversion of 350 million tons of heavy fuel oil for shipping would also require refinery investments in the order of euro 70-100 billion.

These net additional carbon dioxide emissions into the atmosphere, resulting from a switch to cleaner low-sulphur shipping fuel, could be partly compensated by smaller carbon dioxide emissions at sea, because the carbon content per unit of energy of distillate fuels is lower than that of heavy fuel oil. However, the overall balance is still unclear, because there are indications that older ship engines, designed for the traditional bunker oil, may not be able to use the full potential of the new and more refined fuels.  Because many of the older engines have been designed to burn rougher fuels (bunker oil) they might, according to some experts, actually consume an equivalent or even a somewhat larger amount of the more refined fuels.

We have not been able to find out, what is the truth about this matter. The main problem is, that the actual consumption of most older engine types with the proposed more refined post-bunker fuels has never been tested by anybody. For this reason we heard dramatically differing opinions about the matter when we interviewed ship engine experts from different countries (everyone of whom refused to be quoted, on this subject).

***Fig 5**. Oil Refinery Emissions*

## Shifting to Liquefied Natural Gas

According to the representatives of Gasum, the joint natural gas company of the Russian Gazprom and the Finnish Fortum, between 1 and 3 per cent of the liquefied natural gas typically escapes unburned through the engines into the atmosphere, in the form of methane.

On a long run, it might be possible to reduce the problem with improved LNG engine technology. According to an LNG engine manufacturer who was willing to discuss the problem with us, the best modern engines, equipped with an oxidising catalyzer, can probably reduce the amount of unburned gas to less than 0.1 per cent. However, this claim is still to be verified by independent research, and it is not known how the emissions will develop when the new engines become older and begin to wear down.

Significant amounts of gas leak into the atmosphere also during the manufacturing of LNG and 0.5 per cent of natural gas is lost during handling and transport, according to the official statistics of the European Union. Another study concluded that the methane emissions from the Russian natural gas export network might amount to approximately 0.7 per cent of the gas arriving at Russia’s western borders.

These figures do not include the amounts released into the atmosphere during the primary production of natural gas, which seem to be the most significant source of loss. According to current  EPA (the US Environmental Protection Agency) estimates 3.2 per cent of all methane produced for fuel purposes could be lost during the production phase as direct releases into the air, as a global average. The main sources are leaks from machines and valves. There is, however, a great uncertainty in the natural gas emission figures, especially concerning the emissions during the primary production phase.

If just 2 per cent of the gas is lost into the atmosphere unburned LNG loses its climate benefits compared to oil, even when we use a one-hundred-year perspective in the calculations.

Because a methane molecule contains five atoms, it is a much more efficient greenhouse gas than carbon dioxide, which only has three atoms. As long as a methane molecule remains in the air, it heats the planet with the efficiency of approximately one hundred carbon dioxide molecules. However, methane has a shorter life-span than carbon dioxide. Therefore, the relative importance of methane and carbon dioxide as greenhouse gases depends on the time-frame used in the calculations.

At the moment roughly one half of the heating impact of all the extra, man-made greenhouse gases in the air is due to methane. However, if we take into account the fact that most of the methane will soon be gone, while the amounts of carbon dioxide will keep on accumulating, decade after decade, we must discount the heating impact of methane. With a 20-year time-frame the heating impact of methane is only 66 times more than that of carbon dioxide, and with a 60-year time-frame it is only 20 times more. If we use a one-hundred-year perspective in the calculations, direct emissions of methane represented only 14.3 per cent of all global anthropogenic greenhouse gas emissions in 2004.

## Palm Oil and Other Biofuels

Biofuels are another interesting and important alternative. For the ships, there are at least two different options, besides biogas (methane produced by bacteria). One is biodiesel, esterized vegetable oil. The other option is bio-oil, meaning non-esterized, triglyseride-formed, (almost) non-processed vegetable oil. The last alternative would be the cheapest. It would also save some energy, because the esterization of biodiesel typically costs between euro 50 and 100 per ton, and consumes approximately 15 per cent of the original energy content of the plant oil.

Approximately 350 000 square kilometres of palm oil plantations could produce bio-oil for all the world's present merchant ships, assuming that they would use the new oil palm varieties which provide approximately 10 tons of palm oil per hectare per year.

Palm oil has recently acquired a very bad reputation among environmentalists, because Indonesian companies have converted millions of hectares of peatland rainforests to oil palm plantations. Oil palms planted on peatlands require draining, and the establishment of oil palm cultivations on peat soils has thus led to rapid oxidation of peat, typically releasing between 10 and 15 tons of carbon per hectare per year into the air, in the form of carbon dioxide. Moreover, draining the surface layer of peat exposes the peatlands to forest fires, which can burn a metre of peat during a single season. This is, obviously, not a good way to reduce greenhouse gas emissions. According to the latest estimates the Indonesian peat fires and the slow oxidation of peat might now annually release something like 500 million, and possibly 800 million, tons of carbon.

Oil palm plantations are not the only reason for all this destruction. Peatland rainforests have also been converted to pulp tree plantations and rice fields. Illegal and legal logging and shifting cultivation have played important roles in the process. But it is undeniable, that oil palm plantations have rapidly become a very significant part of the problem.

Oil palms could, in theory, be grown everywhere in the moist tropics, in an area amounting to approximately 2.5 billion hectares. This includes at least 1.5 billion hectares of different kinds of clear-cuttings, crazing lands, cultivated fields, fallows, man-made grasslands and artificial waste-lands, which were once tropical rainforests, but whose present biodiversity is low or extremely low. Some of these areas could be converted to oil palm cultivations without causing no further loss of biodiversity, and in a way that would often increase, and not reduce, the amount of organic carbon stored in the soil and in vegetation. Oil palms produce a much better crop on mineral than on peat soils.

Both important oil palm species, the African oil palm (Elaiesis guineensis) and the Amazonian oil palm or the peach palm (Bactris gasipaes) could also be grown in many actual rainforests without felling the larger trees or destroying the rainforest. Both species were, in their natural forms, part of the undergrowth of a rainforest. The Amazonian oil palm was first domesticated in Beni, Bolivia and then quickly spread to all parts of Amazonia. It seems that it used to be the second most important food crop, after cassava, for practically all the people who were living in Amazonia before the arrival of the Europeans. Similarly, the African oil palm was widely cultivated by most of the people living in the tropical moist forest zones of Central and Western Africa, before the African civilizations were destroyed by European colonialism. Because of several millennia of domestication and breeding work by the rainforest peoples and other peasants of West and Central Africa and South America, there are still billions of oil palms growing wild in the Amazonian and Central African rainforests.

Besides the actual palm oil, oil palm cultivations also produce huge quantities of palm oil effluent. It can be used as fodder or processed to human food, or used as raw material for biogas. If the biogas option is selected, the amount of methane that can be produced contains almost as much energy as the actual palm oil. The palm hearts are edible, and they are quickly becoming more popular as human food in a growing number of countries.

Last but not least, oil palms produce huge quantities of woody material: palm trunks, palm fronds and empty fruit shells. The average production of this kind of woody material in the well-managed Malaysian farms amounts to roughly 20 tons of dry matter per hectare per year, when the average of the whole growing cycle is taken into account. Palm biomass has a very high cellulose content, more than 80 per cent, so it forms an excellent raw material for paper, cardboard, plywood and other construction materials. Malaysian scientists have proved, that it is even possible to make many car parts from oil palm biomass, which would of course make the cars lighter and thus reduce their greenhouse gas emissions. The Malaysians have even experimented, successfully, with different types of composite cements which have been partly based on oil palm biomass.

In other words, oil palms could assist a very wide spectrum of industries to reduce their greenhouse gas emissions, assuming that the production can be organized so that it will not destroy the remaining areas of megadiversity (natural rainforests) or lead to the burning or oxidation of deep tropical peatlands.

If the shipping companies would express, for the Government of Indonesia, their interest in palm oil produced in ecologically and socially sustainable ways, they could probably make an important and constructive contribution into the efforts to save the huge carbon stores and the remaining biodiversity of Indonesia’s remaining (peatland) rainforests.

# COMPARING THE DAMAGES: PUBLIC HEALTH VS GLOBAL WARMING

Almost 70 per cent of the ships' emissions enter into the atmosphere within 400 kilometres from the nearest coastline. Pollutants originating from ships may be transported several hundred kilometres and sometimes for even much longer distances. Sulphur irritates human lungs and thus increases the risk of respiratory infections like bronchitis and pneumonia, as well as chronic and often lethal lung diseases like emphysema. Soot and other kinds of small particles seem to contribute to the development of atherosclerosis, and increase the risk of several types of cancer. According to one, often-quoted study shipping-related particulate matter emissions might be responsible for approximately 60,000 premature deaths, annually.

Most of these deaths occur near the coastlines of Europe and Asia. Shipping contributes to air quality problems, above all, due to sulphur dioxide ($SO_2$) and nitrogen oxide ($NO_X$) emissions. Deposition of sulphates and nitrates also results in acidification and eutrophication in sensitive areas. In some coastal areas, for example in parts of Scandinavia, shipping accounts for 20-30 per cent of deposition of these pollutants.

***Fig 6.*** *Ship emissions have health impacts*

The acidity of the oceans' surface layer is also increasing. The pH of the surface layer has already dropped from 8.2 to 8.1, which means that the acidity or the concentration of active hydrogen ions in the surface water has increased by 30 per cent (the pH scale is logarithmic). This is a grave problem that could lead to serious consequences during the next fifty or one hundred years, but it has very little to do with the ships' sulphur emissions. The problem is caused by the more than ten billion tons of carbon dioxide which annually dissolve into the oceans in the form of carbonic acid. Because the quantity of active hydrogen ions produced by carbon dioxide is hundreds of times larger than the quantity coming from the ships' sulphur emissions, it would be very misleading to discuss this problem in connection of the bunker oil issue.

In any case, the decision to move away from the bunker oil is based on the above-mentioned assumptions about the health impact of the ships' sulphur emissions. The concern is legitimate. The problem is that in the IMO negotiations it was automatically assumed that the recommended measures will inevitably and with certainty bring with them important public health benefits, even though there never was any proper risk assessment, and the different possible outcome scenarios were never fully analyzed.

Two issues are especially relevant, in this context. The other one is the risk, that the IMO treaty will increase the ships' fuel costs so much, that it will, in some cases, become more convenient to transport many goods by lorries, instead of ships. This is a very real possibility whenever the distances are relatively short, like, for instance, around the Baltic Sea.

Shifting freight from ships to trucks is not a good idea, because trucks also have diesel engines, which also produce large amounts of small and nanoparticles that contribute to the development of cardiovascular and lung diseases. For each ton-kilometre of freight, trucks burn several times more diesel oil and produce many times more greenhouse gases than ships. Trucks have to use land routes, which means that they release their harmful particle emissions straight into the middle of human habitation. The most important transportation highways are often situated in very densely populated areas. Trucks emit almost no sulphur, but they produce very large quantities of other types of particles known to be at least as harmful for human health. In addition to this comes the increased risk of road accidents.

It would be important to assess, whether the IMO treaty could actually, in some cases, lead to notable increases in people's real exposures to dangerous particle emissions. If this seems likely, the treaty should not be enforced before a proper solution is found to the problem. If the only real rationalization of the treaty does not hold water, it must not be implemented. It would not really make much sense to accelerate global warming and spend a lot of money, if the result would turn out to be an increase in the quantity of dangerous particles entering human lungs.

Besides this, it would have been important to compare the predicted public health benefits from the sulphur emission cuts with the potential new health problems arising from accelerated global warming.

Most of the human population on our planet already lives in areas, where temperatures are, at least for most of the year, above the range that would be ideal for human health. Too cold and too warm temperatures both increase the risk of numerous different diseases, including strokes and heart attacks. Also, the higher the temperatures become, the more aggressive our environment becomes, in terms of dangerous bacteria, viruses, protozoa and parasites.

According to one estimate the climate change that has already taken place is now causing the premature loss of 160,000 lives per year from malaria, malnutrition, diarrhoeal disease, heat waves and floods, compared to what could have been expected if the global temperatures had remained at the average level prevailing during the years 1961-1990. The World Health Organisation has produced almost similar figures. The Great Russian Heat Wave of 2010, which doubled the mortality rates of Moscow in July, could be an early example for what might be in store for us.

However, the present problems are still tiny compared to what might happen if the world heats up by several full degrees Celsius.

The International Rice Research Institute (IRRI) has pointed out, that rice crops are extremely vulnerable to increased night temperatures. If night-time temperatures rise above 34 degrees centigrade for more than one hour when rice is flowering, the heat will sterilize the pollen. For this reason IRRI has estimated, that we might lose 15 per cent of the world's rice crop for each degree of global warming. Rice is the staple food of more than two billion people.

According to Australian laboratory studies cassava will produce almost no root bulbs if the air's carbon dioxide concentrations double. At the same time, the hydrogen cyanide content of cassava leaves would increase so much, that they would in practise become poisonous for human beings. In other words, we will lose one of our most important food crops – the staple food of at least 600 or 700 million mostly very poor people – if the carbon dioxide content of the atmosphere will increase too much.

Global warming should increase rainfall, but in most cases the evaporation of water from agricultural soils will increase much more than the amount of rain. According to the Intergovernmental Panel for Climate Change the world might soon have up to five billion people suffering from an acute shortage of irrigation water, if the world will heat by a few degrees centigrade during this century.

James Hansen, the leading climate scientist of NASA, has said that on the light of the new observations in Greenland and in the West Antarctic, it looks possible, if not probable, that the sea level could rise by up to five metres during the next one hundred years or so. At the moment more than one half of humanity lives on the same coastal flatlands that would be threatened by rising sea levels, salt water intrusion and stronger typhoons and hurricanes. A substantial percentage of our first-quality cropland is also situated on the same coastal flatlands.

The melting of the Himalayan glaciers is a direct threat to the dry season flows of Huangho, Yangtze, Mekong, Ganges, Indus and many other major Asian rivers. If the glaciers lose too much ice, the water and food supply of at least two billion people will be in danger.

Most climate scientists agree, that a global warming amounting to several full degrees centigrade would also lead to the strengthening of the so called El Nino Southern Oscillation, which would mean recurring super-droughts in large parts of Africa, Asia and Latin America.

What will happen for the human health, if super-droughts become more common, the Himalayan glaciers melt, sea levels rise by a couple of metres, evaporation rates increase, the destructive power of typhoons and hurricanes multiplies, rice and cassava will become almost useless as food crops and dozens of other serious problems caused by global warming will fall on us, almost simultaneously?

It would be ridiculous to even try to present precise figures on what kind of morbidity and mortality rates could be expected in such a situation. However, if we will not halt global warming, the future generations will be faced with widespread social destabilization, water shortages and famine. What this could mean from the viewpoint of public health, depends on the level of social destabilization that will be reached before the crises is over.

At present people in the most well-off countries can expect to live, on average, approximately eighty years. In the most seriously destabilized countries the average life expectancy is less than half of this, under forty years. It is not difficult to imagine, that something like this might become the norm for much, if not most, of the world, if we fail in our efforts to curb the global warming.

However, what if the social destabilization continued even farther, so that we would reach the mortality levels that were present in South Asia during the vast El Nino famines of the Late Victorian era, or which were the norm everywhere in the 18th century? If this would become the new standard, the average life-span of humans would drop to less than twenty years, to less than one quarter of what has now been achieved by the world’s well-off or relatively well-off countries.

The adults who lived in the Stone Age sometimes, but very seldom, reached the old and mature age of thirty, but most of them died before their twentieth birthday. The skeletons of the children do not preserve well, so we do not know the exact rate of infant and child mortality during the Paleolithic and Neolithic eras. However, if we assume an infant and child mortality amounting to fifty per cent, the average life-span of people during the Stone Age was a little bit less than ten years. If we assume that the infant and child mortality was seventy per cent, the average human life-span during the Stone Age drops to the maximum of seven years.

In a future world inhabited by seven, nine or ten billion people, very high annual mortality figures will be produced, if the average human life-span drops to the level of the seriously destabilized countries of our own time, not to say anything about the standards typical for the 18th century or for the Stone Age.

It is impossible to say anything accurate about this, because we cannot predict how bad the situation would become. Unfortunately, almost any figure is as good as any other. For instance Stone Age mortality among a population of seven billion would mean 400 – 1,000 million deaths per year, and a 1800th century mortality in a world of seven billion people would amount to 300 – 400 million annual deaths. The present human mortality is a little bit less than 60 million per year, with a world population of slightly less than seven billion.

The potential human consequences of a full-blown greenhouse catastrophe could well be several full orders of magnitude larger than the present costs for human health from the moderate global warming that has already occurred, because the warming that has taken place, this far, has not yet been able to destabilize our societies in any major way.

From the viewpoint of public health, the best option would probably be to cut the sulphur emissions in the Special Emission Control Areas, but allow the ocean-going ships to use bunker oil, even in the future.

On the sea lines relatively close to densely populated areas, the ships’ particulate emissions can reach people’s lungs with a certain probability. In this kind of areas it probably makes sense to cut the ships’ sulphur emissions, except when this would lead to shifting the freight from ships to trucks.

If the freight remains in ships, it is possible to cut the ships’ sulphur emissions in areas that lie relatively close to the shore, without accelerating the global warming. The marine areas relatively close to the shore typically receive heavy doses of all kinds of pollutants from the land, and a shortage of cloud condensation nuclei is therefore a relatively rare occurrence. However, when the move away from bunker oil replaces ships with trucks, both the small particle emissions that are harmful for human health, and the carbon dioxide and soot emissions heating the climate, should actually increase, in a rather substantial way.

When a ship is travelling over a faraway marine region with only a very few cloud condensation nuclei, its emissions are not likely to harm humans, but often provide a very strong globe-cooling impact.

# WHAT SHOULD BE DONE – COMPARING THE POLICY ALTERNATIVES

The purpose of the preceding chapters has been to present the problem.

In this chapter we try to outline a few different policy alternatives, and to assess their consequences for climate and for public health.

## 1. The Enforcement of the IMO Convention in its present form

At the moment this must, unfortunately, be seen as the baseline scenario, because many strong interest groups are pushing things towards this direction. This most probably includes the big oil and gas companies and some of the companies that would like to manufacture the new LNG-using ships and their engines. Because the global Peak Oil is approaching (we may, actually, already have reached it) the oil industry can no longer increase the amount of the oil it sells, counted as barrells. In the future the oil companies relying on fossil fuels can only expand their profits and turnover if they can process their crude into a more expensive form. For this reason the Big Oil (the six largest, non state-owned energy companies) will almost certainly do its utmost to push the IMO Convention through, in its present form.

However, the public benefits from this policy are not very clear. The pros and cons could be assessed in the following way:

**Pros**

***+ sulphur emission cuts in SECAs would probably bring important public health benefits, and reduce problems related to acidification over the continents***

**Cons**

***- sulphur emission cuts offshore do not have any real importance for public health***

***- global warming might increase by 0.31 w/m$^2$ (or, according to the worst case scenario, by up to 1.4 w/m$^{2)}$, depending on what will be used instead of the bunker oil, and depending on the exact size of the aerosols' cooling impact***

***- the cost for ship-owners might amount to USD 200 billion per year***

***- the required level of investment would make it more difficult to invest in fuel-saving measures, that would also reduce the greenhouse gas emissions, like sail kites, integrated propulsion systems, ducktails and air greasing...***

***- the Convention might increase the ships' greenhouse gas (carbon dioxide and methane) emissions***

***- if the Convention leads to increased carbon emissions from the ships, it will accelerate the acidification of the Ocean's surface layer.***

For these reasons we cannot recommend this option. The IMO Convention must not be enforced, in its present form.

## 2. Negotiating a New Convention that also takes the Greenhouse Gases into Account

According to our opinion, it would make perfect sense to abandon the present convention, and to re-negotiate a new treaty with a somewhat wider scope.

The COPs (Conferences of the Parties) of the United Nations Framework Convention on Climate Change will, sooner or later, force the shipping sector to reduce its carbon dioxide emissions.

The IMO Convention could be re-drafted so that it would pay attention to both the sulphur emissions and the carbon dioxide emissions, at the same time.

It is economically disastrous to first enforce a treaty that cuts the sulphur emissions in a way that might increase the methane and carbon dioxide emissions, and then negotiate a separate treaty that would force the same shipping companies to reduce their carbon emissions.

One opportunity for re-negotiating the convention could arise during the review process in 2018.

## 3. Replacing Sulphur by Dispersing the Ship Routes

Maritime traffic concentrates on a small number of densely packed shipping routes between the main harbours, because ships favour the shortest routes. They want to deliver cargoes to their destinations as quickly as possible. Companies that own the cargoes have invested capital in them, and they can get their money back and make profit only after the containers have been delivered. If the shipping routes and ships were dispersed more evenly over the oceans, the sulphur dioxide produced by the ships would most probably produce many times more marine stratocumulus clouds. Outside the Arctic and Antarctic regions, such clouds have a strong cooling impact on our planet.

If the freight ships of the future had both a diesel engines and a wind propulsion system like a Flettner rotor or a sail kite, and if they aimed at minimizing their oil consumption, they would almost automatically become widely dispersed and scattered over the oceans. When a ship is partially wind-powered, the most direct route will no longer be the route that consumes the least fuel, because wind conditions and the direction of the prevailing winds also influence the calculations.

For a ship equipped both with engines and with sails or a sail kite it would often make sense to use a much longer route. This means that even if the ships equipped by sail kites would consume 30 or even 50 per cent less oil and use fuel that only contained 0.5 per cent sulphur, the ships’ combined capacity to produce clouds and to make them more reflective and long-lasting, might still remain at roughly the present level.

The problem with this alternative are the LNG ships. If LNG will become the cheapest fuel alternative in the Post Bunker Oil World, most of our future ships might soon be running with LNG, in which case dispersing their routes would do (almost) nothing to cool the climate.

## 4. Replacing Bunker with Bio-Oils

It has been remarked, that non-processed, non-esterized vegetable oils (bio-oils) might constitute an alternative solution to the dilemma, if they can be produced in an ecologically and socially sustainable way.

In purely economic terms, bio-oils should be able to compete with liquefied natural gas. Burning them would produce nitrogen-based aerosols, ash particles and hundreds of different organic carbon compounds.

In other words, some bio-oils might produce as many or almost as many cloud condensation nuclei as the burning of sulphur-rich bunker oil, thus maintaining the anthropogenic cloud parasol over the oceans, even though the bio fuel emission tests seem to indicate that somewhat less particulate matter (PM) is produced.

Bio-oils do not have LNG's methane problem, and they can be produced in various carbon-negative ways. The particles produced by burning bio-oil, however, can be harmful to people's health if they are carried over populated land areas, but when they act as cloud condensation nuclei over the oceans, they fall down with the rain drops and cannot be inhaled in human lungs.

This option might be a sustainable long-term solution to the problem. Unfortunately, we do not yet know enough on the qualities of the various bio-oils, from the cloud-forming perspective. We do not know whether their flue gases are as effective in assisting the formation of highly reflective clouds as the sulphur-rich flue gases produced by burning bunker oil.

It would be important to organize a number of trials with different kind of bio-oils, to see how many cloud condensation nuclei they produce, how effective the particles produced by them are in assisting the formation of clouds, and how reflective and how long-lasting the clouds midwifed by such particles would become.

## 5. Adding a Climate Protocol into the IMO Convention

According to our opinion, the best policy alternative might be to add a separate Climate Protocol into the already existing IMO convention, to offset the extra warming “caused” by the reduced aerosol emissions.

Such a protocol could give ocean-going ships a special permission to use ordinary, sulphur-rich bunker oil, whenever taking a less-used route that would bring the ship into a region with few or relatively few cloud condensation nuclei.

In other words, the costs of a longer route would be richly compensated by the possibility of using a cheaper fuel. In the northern waters such a possibility should only exist in summer, in the tropical and subtropical waters it should be available throughout the year.

It would be better to use fuel containing only very little sulphur in the North Atlantic and other northern seas during late autumn, winter and early spring, because clouds forming over the northern marine regions often drift even farther north, where they can then produce a mild heating impact during the spring and autumn and a massive heating impact during the winter. Only clean fuels should be used in SECAs.

This kind of a climate protocol would also produce a strong incentive for the ships to invest in sail kites and in other kinds of integrated propulsion systems. Sail kites or sails would make it cheaper for the ships to use a longer route, and if we also add the possibility to use bunker fuel, the combined economic incentive would become major.

## 6. Using additives in fuels instead of sulphur.

It would, of course, be possible to replace the sulphur by some kind of additives that would provide similar cloud condensation nuclei for the cloud droplets. Theoretically, it might be possible to find something that would be as efficient as cloud condensation nuclei but less harmful for people’s health. However, particles have to have a certain size to be effective as cloud condensation nuclei. This puts all of the possible materials, almost automatically, roughly in the same range of particle sizes that are likely to be harmful for human health. It would be next to impossible to know, in advance, whether the particles produced by the new additives would be less harmful or more harmful for the people than sulphur.

Moreover, it does not make great economic sense to first remove something with great cost and then add something to replace it, again with some extra costs.

## 7. Geoengineering.

At least in theory, investing in geoengineering (the deliberate manipulating of the Earth's climate to counteract the effects of global warming from greenhouse gas emissions) research and projects to counteract the rapid warming caused by reduced sulphur in fuel, would also be an option.

Geoengineering is a controversial issue and should not be used to delay cuts in greenhouse gas emissions. Resources should be allocated to find the best and safest options should we ever need them.

All geoengineering schemes come with a price tag and with risks that are difficult to assess and quantify. Not doing anything for the ocean-going ships’ sulphur emissions could also be seen as geoengineering, but it would be a relatively safe form of the art, and the costs would be negative, most probably 200 billion euros per year less than nothing.

## 8. Installing Scrubbers in the Ships

It would also be possible to install sulphur-removing scrubbers into the ships, and to require that they are used near the shoreline, but not at the open ocean. If vessels were fitted with scrubbers, they would become capable of reducing their sulphur emissions, whenever this is desirable and necessary. At the open ocean they could just bypass the scrubbers and burn sulphur-rich fuel.

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