Carbon Dioxide Emissions Valuation and its Uses

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Abstract

The purpose of this paper is to bring out the frequently used definitions of the carbon price for one tonne of carbon dioxide avoided or reduced. This per unit cost plays an important role in estimating the benefit of avoiding greenhouse gas emissions or estimating the damage occurred when such gases are emitted. The economic valuation of carbon is essential for various purposes: designing environmental policies like optimal taxes and evaluating the economic efficiency of projects. Furthermore, the disutility cost can be used in cost benefit analysis and therefore in risk assessment. A framework called Formal Safety Assessment (FSA) is currently, the major risk assessment tool that is being used for policy-making within the International Maritime Organization (IMO). Therefore the work can also be also viewed within the framework of FSA, Cost-Benefit Analysis and similar risk assessment and policy evaluation analyses.

Keywords

Cost of Carbon Dioxide; Cost Benefit Analysis; Cost of Averting a unit mass of emissions; Marine Risk Assessment;

1. Introduction

Human activities alter the atmospheric composition of earth which may lead to climate change. This view has led to the United Nations Framework Convention on Climate Change (UNFCCC) with the agreed objective *"to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system"*(see Article 2 of the Rio Convention). The stabilization of concentrations of atmospheric CO2 will require significant reductions in global emissions of CO2 in the future but the resultant temperature from stabilizing these concentrations at various levels (e.g., 450 ppm, 550 ppm, etc.) depends on many factors. Models estimate that the global mean surface temperature arising from a doubling of CO2 concentrations is between 2^{o} C and 4.5 ^{o} C (IPPC, 2007).

Air pollution from ships is also at the center stage of discussion by the world shipping community. It is known that fossil fuels such as the marine bunkers contain high percentage of carbon and hydrocarbons and the burning of these fuels produces carbon dioxide (CO_2) which is one of the Greenhouse Gases (GHGs). Carbon dioxide enhances radiative forcing and contributes to global warming. Global Warming is the increase in the average temperature of the Earth's near-surface air and oceans. An increase beyond the normal can cause sea level to rise, decreased snow cover in the Northern Hemisphere and so on. Therefore, activities that emit carbon dioxide may present a threat to the society. For international shipping, the Kyoto Protocol gave IMO -the International Maritime Organization- the task of tackling bunker emissions but until now not a single binding measure has been agreed upon. Although some regulation exists for non- GHGs, such as SO_2, NO_x and others, shipping has thus far escaped being included in the Kyoto global emissions reduction target for CO_2 and other GHGs (Psaraftis and Kontovas, 2009).

In order to guide the development of relative regulations, look among the alternatives and eliminate those that are not cost effective and, finally, support regulatory decision, these emissions have to measured and valuated. In the scope of the present paper we assume that both carbon dioxide emissions as well as their reduction after application of control measures can be measured with some confidence. However, this assumption may not necessarily be valid, as was demonstrated in several studies that use modeling to estimate emissions. Note that even the same study produced a range of estimates. For example, in the latest study prepared for IMO total CO_2 emissions from shipping (both domestic and international) are estimated to range from 854 to 1,224 million tons (2007), with a 'consensus estimate' set at 1,019 million tons (Buhaug, et al., 2008). There is indeed a pressure to the IMO to adopt measures to curb carbon dioxide emissions. These measures should be able to reduce emissions at a logical cost to the society, this means that cost of regulation regulations has to be less than the benefit to the society. Therefore, the biggest challenge is to monetize carbon dioxide emissions, that is, put a monetary value to them. In some industries these values are sometimes used in the framework of broader cost benefit analysis to assess whether a particular policy is expected to improve or reduce the overall welfare of society. The analysis has to take into account all relevant costs and benefits (including impacts on climate change from averting carbon dioxide emissions).

Note that throughout this paper, reference to 'carbon price' means the cost per unit of carbon dioxide equivalent emissions avoided or reduced. Carbon dioxide equivalents (CO_2 eq) provide a standard of measurement against which the impacts of releasing (or avoiding the release of) different greenhouse gases can be evaluated. According to IPPC (2007) every greenhouse gas (GHG) has a Global Warming Potential (GWP), a measurement of the impact that particular gas has on 'radiative forcing'; that is, the additional heat/energy which is retained in the Earth's ecosystem through the addition of this gas to the atmosphere. Global Warming potentials for the greenhouse gases regulated under the Kyoto Protocol under a 100 year timeframe are as follows :

Carbon dioxide has a GWP of 1
Methane has a GWP of 21
Nitrous oxide has a GWP of 310
Sulphur Hexafluoride has a GWP of 23.90

Carbon dioxide emissions represent an environmental externality and the value of carbon emissions is not easily monetized. The greatest difficulty in carbon valuation is that environmental goods have no price since they are not marketable. One of the possible ways advocated by some circles to reduce emissions is the use of market based instruments such as carbon trading. For instance, an Emissions Trading Scheme (ETS) is used in the EU as an instrument for several industries. In that sense, a market is created where units that permit the right to emit are traded and therefore by definition this creates a market price which can be used in cost effectiveness analysis. In the current paper we review schemes of CO_2 market prices as a possible way to determine the cost effectiveness of carbon emissions' reduction actions and as a way to measure the benefits from abatement measures which is also equal to the damage cost to the society from emissions. Furthermore, within this paper we elucidate the frequently used definitions of 'carbon price'.

According to the Intergovermental Panel on Climate Change (see IPPC,2007), Carbon Dioxide (CO_2) is *"a naturally occurring gas, and a by-product of burning fossil fuels or biomass, of land-use changes and of industrial processes. It is the principal anthropogenic greenhouse gas that affects Earth's radiative balance. It is the reference gas against which other greenhouse gases are measured and therefore it has a Global Warming Potential of 1."*

Furthermore, Carbon Price is *"what has to be paid (to some public authority as a tax rate, or on some emission permit exchange) for the emission of 1 tonne of CO_2 into the atmosphere."* In the models and the IPCC Fourth Assessment Report (see IPCC,2007*), "the carbon price is the social cost of avoiding an additional unit of CO_2 equivalent emission. In some models it is represented by the shadow price of an additional unit of CO_2 emitted, in others by the rate of carbon tax, or the price of emission-permit allowances. It has also been used in this Report as a cut-off rate for marginal abatement costs in the assessment of economic mitigation potentials."*

According to the literature, the most important ways to price carbon emissions are through:

· Social Cost of Carbon (SCC) or Damage Cost
· Marginal Abatement Cost of Carbon (MAC) or Avoidance Cost, and
· Market Prices (e.g by using EU Emissions Trading Scheme (ETS) Futures Price)

This paper will comment on these methods in order to elucidate the frequently used definitions. Moreover, unlike the other, more theoretical approaches, a more realistic approach will be analyzed. In the case of environmental externalities we mostly talk of non-market impacts and in order to measure environmental damages economists either indirectly link environmental resources to some market goods or even construct a hypothetical market in which people are asked to pay for these resources. However, in the case of carbon dioxide emissions the existence of a trading scheme within the European Union allows us to use the actual amounts of money that companies pay. However, we note that the exchange price varies over time and may not be the optimal one, which will lead to the failure of this market-based approach.

The paper is structured as follows. Section 2 presents the most frequent definitions of carbon price and Section 3 comments on assessment frameworks and policy evaluation analysis, such as cost benefit analysis, and investigates the uses of carbon valuation. Finally, Section 4 presents the conclusions.

2. Carbon Dioxide Valuation and Definitions

2.1 The Social Cost of Carbon (SCC)

Stern defines the Social Cost of Carbon as a measure of *"the total damage from now into the indefinite future of emitting an extra unit of GHG's now"* (Stern, 2007) and the IPCC as "*the discounted monetized sum (e.g. expressed as a price of carbon in $/t$CO_2$) of the annual net losses from impacts triggered by an additional ton of carbon emitted today. According to usage in economic theory, the social cost of carbon establishes an economically optimal price of carbon at which the associated marginal costs of mitigation would equal the marginal benefits of mitigation."*

To calculate this damage cost,the atmospheric residence time of carbon dioxide must be estimated, along with an estimate of the impacts of climate change. The impact of the extra tonne must be converted to the equivalent impacts at the time when the tonne of carbon dioxide was emitted and the impacts have to be discounted over time (Yohe et al., 2007).

According to the Intergovermental Panel on Climate Change (see 2007 IPCC report), peer-reviewed estimates of the SCC for 2005 have an average value of $12 per tonne CO_2 (tCO_2). In addition, the European Commission assumed an average carbon price of €39/tCO_2 in its Impact Assessment of the January 2008 Proposed Climate Change and Renewable Energy Measures from 2012 to 2020 (Curtin, 2008). Furthermore, Tol (2008) considered 211 estimates of the SCC in a meta-analysis from data gathered from a total of 47 studies and calculated a mean of $28/$tCO_2$ and $15/$tCO_2$ for all estimates and peer reviewed estimates respectively. For a literature review of SCC estimated the reader is referred to Comhar (2008).

The wide range of estimates is explained mostly by high uncertainties in the science of climate change and especially in the potential catastrophic impacts associated with it and with different choices of discount rate. Given that SCC *"is the present discounted value of the future stream of costs resulting from today's emission of a new unit of carbon, future costs are discounted, or reduced in value"*, therefore in general tend to be rather low. As a result, less weight is given to policies, which means that no strong actions are being recommended,see Shanton and Ackerman (2008).

2.2 Marginal Abatement Cost (MAC)

Another approach that avoids the high uncertainties associated with assessing the SCC is to assess the costs of avoiding emissions. These are also referred to as avoidance costs or mitigation costs and their calculation is based on a cost-effectiveness analysis that determines the least expensive cost option to achieve a required level of greenhouse gas emission reduction.

The figure below presents an example of a **marginal abatement cost** (MAC) curve published in a global study by McKinsey in 2007 (Enkvist et al, 2007). Figure 1 shows the annual abatement needed to achieve stable atmospheric greenhouse gas concentrations of 500 ppm (parts per million), 450 ppm and 400 ppm of CO_2-equivalents. For example, a global emissions reduction of 26 Gtons of CO_2e per year would stabilize greenhouse gas concentrations at 450 ppm of CO_2-eq, and that reduction would need all the abatement measures up to a cost of €40 per ton of CO_2e

It is very interesting to note that according to Figure 1 the most cost-effective abatement measure is building insulation. There are indeed many measures that have a negative abatement cost – that means that carry no net life cycle cost, they come free of charge. However, the lowest cost measures are mainly efficient but cannot deliver the required emissions reductions by themselves. Policy making has to move up the cost curve progressively to more expensive technologies in order to achieve stable atmospheric greenhouse gas concentrations.

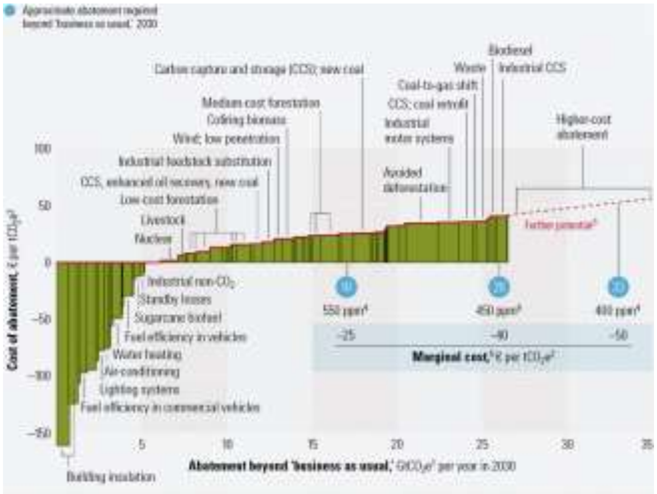

Figure 1: Cost curve for greenhouse gas abatement measures. Source: Enkvist et al., 2007

In a similar way, marginal abatement costs have been estimated for shipping. For example, Figure 2 presents the cost per tonne CO2 averted for reduction option for the whole fleet and their potential for cutting emissions in the year 2030, see DNV(2009). Similarly curves can be constructed for fleet segments.

Figure 2: Cost per reduction option on world fleet
Source: DNV, 2009

Figure 2 summarizes technical and operational measures to reduce shipping emissions from ships in 2030. The height of each bar represents the average marginal cost of avoiding a ton of CO2 given that all measures on its left are already applied and the width represents the potential of that measure to reduce emissions. As one may notice there are several measures that have a negative cost. These seem attractive to policy makers and should be considered for mandatory implementation. Moreover, policy makers given limited budgets should adopt reduction measures according to their reduction target and the cost per measure. Furthermore speed reduction by increasing the efficiency of ports has the greatest potential to reduce emissions among all measures that have a negative cost per tonne of carbon dioxide averted and reducing speed has the greatest potential among all measures. The reader is referred to Psaraftis and Kontovas (2009) and Psaraftis et al. (2009) for more information on the effectiveness of speed reduction measures and their tradeoffs.

If the carbon price derived by using MAC curves and used in policy appraisal *"is simply the most expensive measure in the strategy to meet the budgets and other overall government targets"* (f.e. emission reduction target, or stabilization levels), then any policy can be easily judged against others (FOEI, 2008). Therefore, measures that cost up to a specific threshold should be proposed for adoption.

However, MAC estimates have some weak points. First of all, MAC prices depend heavily on emission reduction targets and stabilization targets and, therefore, differ among sectors and countries. Furthermore, they do change massively over time as innovation kicks in with more cost-effective measures (FOEI, 2008).

2.3 Analysis of CO_2 market price

The advantage of using a market price is that it is very "real" – this figure is the one business people use when taking decisions (FOEI, 2008). This approach takes into account already existing market prices, for example the price of a carbon allowance traded in the European Union's Emissions Trading Scheme (ETS) that gives the owner the permission to emit one tone of carbon dioxide. The main disadvantage is that the market price is based on particular sectors and on a number of countries and, thus, does not cover the whole economy.

In general, the area of Carbon Finance and of Carbon Exchanges, in particular, is a bit complicated. For a comprehensive survey of carbon exchange the reader is referred to Bettelheim and Janetos (2009). According to this survey, today there are some 20 carbon exchange initiatives, 11 of which are already trading. They are located in all geographic regions and vary from a simple matching of buyer and seller (Australian Climate Exchange) to auction markets (Asia Carbon Exchange) and from those limited to European Union Allowances (EUAs) and Kyoto Protocol Certified Emission Reductions (CERs) like the European Climate Exchange (ECX).

European Union Allowances, or EUAs, are carbon credits issued under the EU Emissions Trading Scheme to CO2-emitting installations which is currently in Phase II (2008-2012). On the other hand, CER products ensure delivery of Certified Emission Reduction (CERs) units which are credits generated from greenhouse gas emission projects which fall under the Clean Development Mechanism (CDM) defined by Article 12 of the Kyoto Protocol.

In general EUAs are more expensive than CERs and future prices are more expensive than daily (spot) prices. The price of the EUA started to increase steadily already in the early 2005 and during the summer it peaked to over 30 Euros per tonne, see Fig. 3 below. However, in the end of April 2006, soon after the information regarding the true emissions EU of member states was published, the price dropped within a couple of days from almost 30 to below 10 Euros per tonne, see POMAR/MARMET(2007) for a more detailed analysis. It is believed that the cap which was set for Phase I, was stricter than the actual emissions and therefore there was no need to buy extra allowances bringing the price eventually to zero. That is why the Phase I of ETS has been viewed as a failure.

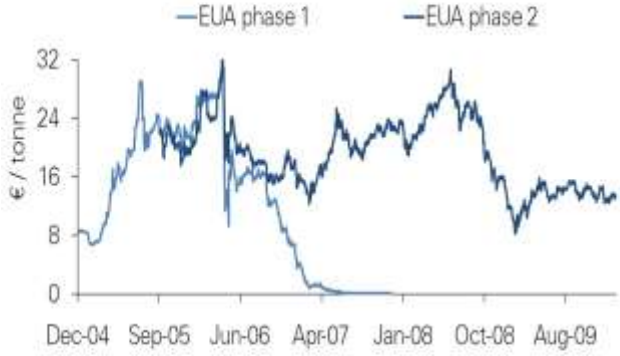

Figure 3. Prices in the EU ETS, 2004-present (Front year contracts for phase 1 and 2) – Source: Point Carbon

Note that if the ETS price is applied to non-ETS sectors the result will be less emissions abatement than needed and, on the other hand, by using the same carbon price across all sectors of the economy should be perceived as fair by companies (Comhar, 2008).. It looks that there is a lot of uncertainty related to carbon price and there is evidence of strong volatility in carbon markets. In is not the purpose of this paper to arrive at a single carbon price rather than present the possible ways of carbon valuation and of its uses as they will be described in the following Section.

3. Uses of Carbon Dioxide Emissions Prices

3.1 The Shadow Price of Carbon

Governments in the context of policy evaluation use one, or a combination, of the above approaches to carbon valuation as the basis for incorporating carbon emissions in cost-benefit analysis and impact assessments of their regulations (DEFRA, 2007). IPCC defines as **shadow pricing** *"setting prices of goods and services that are not, or incompletely, priced by market forces or by administrative regulation, at the height of their social marginal value."*

The 'shadow price for carbon', representing the cost to society of the environmental damage, has been agreed in the United Kingdom. According to the Department for Environment, Food and Rural Affairs (DE-

FRA,2007), the Shadow Price of Carbon (SPC) derived by estimating the Social Cost of Carbon should be used in CBA. According to DEFRA(2007) the difference between the Shadow Price of Carbon (SPC) and the Social Cost of Carbon(SCC) is the following :

"The SCC is determined purely by our understanding of the damage caused and the way we value it, the SPC can adjust to reflect the policy and technological environment. This makes the SPC a more versatile concept in making sure that policy decisions across a range of government programmes are compatible with the Government's climate change goals and commitments."

The Shadow Price of Carbon was set at £25.50 a carbon tonne for 2007, rising annually 2 per cent to account for the rising marginal damage cost over time DEFRA(2007).

Recently, the approach to carbon valuation in UK has undergone a major review, concluded in July 2009 to a MAC-based or "target-consistent" price of carbon that involves setting a value of carbon that is consistent with the level of marginal abatement costs required to reach the targets that the UK has adopted – either at a UK, EU or international level (see DECC,2009). According to the UK Department of Energy and Climate Change (DECC) this approach *"enables more accurate policy appraisal, with respect to the costs and benefits to the UK, and consistency with our European obligations"*. For appraising policies that affect emissions in sectors covered by the EU ETS the 'traded price of carbon' of 21 £/tCO_2eq in 2009 values is recommended whereas for policies that affect emissions in sectors not covered by the EU ETS (the non-traded sector) the 'non-traded price of carbon' of 51 £/tCO_2eq should used (DECC,2009).

In France, the Conseil d'Analyse Stratégique recommends a figure of €32/t CO2, reaching €100 in 2030 is recommended. This value is based on a price of 27 euros proposed in the so-called 2000 Boiteux report, with inflation taken into account. This price is currently adopted to evaluate the profitability of public investments. (Centre d'Analyse Stratégique, 2008).

In the United States, the Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA) have also assigned a dollar value to reductions in CO2 emissions, see US Federal Register (2010). In a joint proposal to establish a National Program consisting of new standards for light-duty vehicles that will reduce greenhouse gas emissions and improve fuel economy. benefits of reducing GHG emissions have been estimated using a set of interim global SCC values. The SCC values vary from $34 to $5 as these represent the estimates associated with the 3% and 5% discount rates, respectively. According to the same document, the average global SCC value used by EPA is **$** 20 per metric ton in 2007 dollars, a value that is recommended to be increased annually using a 3% growth rate.

Moreover, on March 9, 2010, the Department of Energy (DoE) published in the Federal Register a new final rule on energy conservation standards for small electric motors. The new rule's regulatory impact analysis includes a discussion of the social cost of carbon, which is based on a document attached as Appendix 15A to this rule. This document (EPA, 2010) is the result of a federal interagency consultative process involving, among others, the Environmental Protection Agency(EPA), the Departments of Energy (DoE), Transportation (DoT) and the Office of Management and Budget (OMB).The report (EPA, 2010) presents the 'social cost of carbon' estimates to allow agencies to incorporate the social benefits of reducing carbon dioxide (CO2) emissions into cost-benefit analyses of regulatory actions that have small, or marginal impacts on cumulative global emissions. The interagency group selected four SCC estimates for use in regulatory analyses. For 2010, these estimates are $5, $21, $35, and $65 (in 2007 dollars). The first three estimates are based on the average SCC across models and socio-economic and emissions scenarios at the 5, 3, and 2.5 percent discount rates, respectively and the fourth value is included to represent the higher than-expected impacts from temperature change. The central value is the average SCC across models at the 3 percent discount rate. Therefore it is expected that many future analyses will uses the price of $21 per tonne CO_2.

3.2 Efficient Environmental Policies

The authors want to stress out the importance of using the marginal cost in cost effectiveness analysis. Therefore, we present the basic framework in evaluating the effectiveness of policies for addressing environmental pollution controls which draws mainly from Kontovas et al. (2010). In Environmental Economics, criteria for evaluating policies is based on their ability to achieve efficient and cost-effective reductions in pollution. 'Efficiency' is the balance between abatement costs and damages. Furthermore, efficient policy is one that moves the society to, or near to, the point where marginal abatement costs and marginal damages are equal. Since that environmental damages cannot be measured accurately, the cost-effectiveness criterion is the most useful to be employed.

As described in Field and Field(2009), a policy is cost-effective if *"it produces the maximum environmental improvement possible for the resources being expended or, equivalently, it achieves a given amount of environmental improvement at the least possible cost."* In following figure, MC is a typical marginal cost curve, MD a typical marginal damage curve and x* is the point of "efficient" pollution. Note that when talking about prevention of emissions, the benefits of preventing pollution are equal to the damage costs that would occur if the same amount of gases was released to the environment.

Fig. 4 represents the shape of the typical marginal cost and damage functions, and e* is the socially optimal level of emissions. In equilibrium theory, it is worth reducing CO_2 emissions up to the point where the marginal benefits of reduction are equal to their marginal cost. Therefore, the Social Cost of Carbon (which we presented in Section 2.1) is the per unit cost that corresponds to the efficient level of emissions (e*). In that sense, policy makers should invest to any reduction measure to curb emissions that costs less than the SCC.

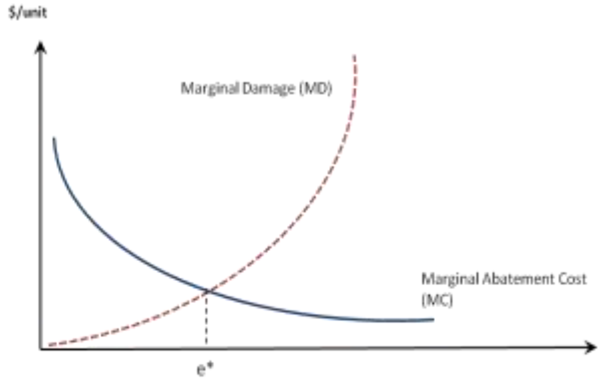

Figure 4: The efficient level of emissions

3.3 Environmental Policy Evaluation

There are many ways to evaluate policies, the most known of which within the scope of this paper are: Cost-Benefit Analysis (CBA), Cost-Effectiveness Analysis (CEA) and Environmental Impact Assessments. Note that in some countries, for example in the United States regulators must prepare regulatory impact analyses (RIAs), which are basically a form of cost-benefit analysis) when proposing major new rules. Under Executive Order 12866, U.S. Government agencies are required, to the extent permitted by law, *"to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs."* Furthermore, before the European Commission (EC) proposes new initiatives it assesses the potential economic, social and environmental consequences by performing Impact assessments (IA) that may include a cost-benefit or cost-effectiveness analysis. By June 2005 the EC has also adopted Guidelines for performing Impact Assessments.

Within the International Maritime Organization, a risk assessment framework called 'Formal Safety Assessment' (FSA) is being extensively used although, currently, it is not mandatory to perform an FSA for new regulations.

Formal Safety Assessment (FSA) was introduced by the IMO as *"a rational and systematic process for accessing the risk related to maritime safety and the protection of the marine environment and for evaluating the costs and benefits of IMO's options for reducing these risks"* (see FSA Guidelines in document MSC circ. 1023/MEPC circ. 392). One of the Steps of FSA and, in general, of similar Risk Assessment tools is to perform an analysis of the costs and benefits (Cost-Benefit Analysis).

We note that it is out of the scope of this paper to comment on the deficiencies of these methods. The reader is referred, amongst others, Kontovas and Psaraftis (2009) and Mishan and Quah(2007) for a discussion on FSA and CBA, respectively . Cost Benefit Analysis and Cost Effectiveness Analysis will be presented in order to explain how the carbon price can be used in order to estimate the damages to the society by emitting one tonne of carbon dioxide or the benefits when a measure or regulations averts the emission of one tonne.

Cost Benefit Analysis (CBA)

CBA is an accounting technique for capturing the advantages and disadvantages of an action in monetary terms, see Krupnick (2004). This action can be a project, a Risk Control Option (RCO), a medical intervention, a policy or any other measure. Subtracting costs from benefits yields the net benefits to society (also referred to as net improvements in social welfare). Actions that improve welfare or well-being are superior to those that reduce it. Furthermore, CBA can be used to cardinally rank them on the basis of their change in well-being. CBA focuses on the aggregate measures of well-being, taking the existing distribution of income as given.

The basic criterion is that if the discounted present value of the benefits exceeds the discounted present value of the costs then the action is worthwhile. This is equivalent to the saying that the net benefit must be positive or that the ratio of the present value of the benefits to the present value of the costs must be greater than one. Theoretically speaking, the higher the ratio the better the regulation is. The above criterion is equivalent to the following:

$$B > C \quad or \quad B - C > 0 \quad or \quad \frac{B}{C} > 1$$

In general, the **cost** component consists of the one-time (initial) and running costs of an RCO, cumulating over the lifetime of the system. The **benefit** part is much more intricate. It can be a reduction in fatalities or a benefit to the environment or an economic benefit from preventing a total ship loss. Cost is usually expressed using monetary units. To be able to use a common denominator, a monetary value has to be given for the benefit too. Here comes the use of the Carbon Price or the Shadow Price of Carbon – that is the price of one tonne of carbon dioxide emitted or avoided.

Probably its main disadvantage is that it seeks monetization of all the effects. Some people feel that it is unethical to place a monetary value on health or mortality risk changes because it seems that CBA places a value on human life, see Krupnick (2004). Without entering into further detail, this view reflects a misunderstanding about the valuation process. This is due to the way that the society perceives risk. An oil spill harms the environment sometimes by killing birds and creates economic damages in the local society f.e in fishing and in tourism. On the other hand, people are not that much aware of the damage of air emissions, e.g. greenhouse gases since the effects in the climate change will take many years to appear and presumably place lower monetary value in the latter case.

Cost Effectiveness Analysis (CEA)

CEA is a particular form of CBA, where the benefits are usually not monetized, and therefore, net benefits cannot be calculated. If instead of placing monetary values we use utilities then the relevant method is called "Cost Utility Analysis", see for example, Mishan and Quah(2007) and Krupnick (2004). Furthermore, in the case of "net cost-effectiveness analysis" any monetized benefits of a policy are subtracted from costs. Usually, in CEA, one calculates costs per unit of an effectiveness measure (such as lives saved). Therefore, while CEA cannot help in determining whether a policy increases social welfare, it can help in the choice of policy that achieves the specified goal with the smallest loss in social well-being and can help rank alternative policies according to their cost-effectiveness (Krupnick, 2004).

The criterion that is applied in CEA is the Cost Effectiveness Index (CEI). Based on the indices defined in the FSA framework we can define the following two indices that can be used when assessing air emissions from shipping.

Gross Cost Effectiveness Index (GCEI)

$$GCEI = \frac{\Delta C}{\Delta R} \qquad (1)$$

Net Cost Effectiveness Index (NCEI)

$$NCEI = \frac{\Delta C - \Delta B}{\Delta R} \qquad (2)$$

where

ΔC is the cost per ship of the action (measure, RCO etc) under consideration [$]

ΔB is the economic benefit per ship resulting from the implementation [$]

ΔR is the change in mass of emissions averted per ship.

The mass of emissions averted can be 'tonnes of CO_2', or 'tonnes of NOx' or any other exhaust gas. Particularly, for the case of Greenhouse Gases (GHG) the notion of CO2-eq can be used.

The criterion in this case is that actions with cost effectiveness index that lie below a specific threshold, referred to as lamda (λ) value, are deemed to be cost effective and should be adopted.

3.4 Uses of Carbon Price in Policy Evaluation

Following the definition of the IPCC Fourth Assessment Report (see IPCC, 2007) that we presented in the Introduction, the carbon price represents the shadow price of an additional unit of CO_2 emitted and it has also been used as a cut-off rate for marginal abatement costs in the assessment of economic mitigation potentials.

Different values are used among various sectors and there is no universally accepted carbon price exists, as clearly demonstrated in the previous Sections. However the use of the carbon price is clear : Suppose that the carbon price is know and is CP. The unit of carbon price is monetary unit divided to mass units, for example $/ tonnes. The damage of an action is the product of the amount of emissions and the carbon price. That is, if the action produces x tonnes of carbon dioxide and the carbon price that we use in our analysis is CP $ per tonnes then the damage is $D(x) = CP(\$/tn)\bullet x(tn)$. Similarly, we can estimate the benefit of an action or policy that reduces emissions by x tonnes. In Cost-benefit analysis we then compare the benefit $B(x) = CP(\$/tn)\bullet x(tn)$ with the implementation costs of the action.

Furthermore, since carbon price has also been used as a cut-off rate for marginal abatement costs in the assessment of economic mitigation potentials, this value can be used as a cost-effectiveness threshold, the lamda (λ) value that was presented in Section 3.3. Among actions the one that achieves the lowest cost-effectiveness is better.

We should finally note that Eide et al. (2009) have defined a net cost effectiveness index to be used within Formal Safety Assessment. According to their work, CATCH (Cost of Averting a Tonne of CO2-eq heating) "*is a measure of cost-effectiveness in terms of the present value of the sum of the discounted current and future benefits and costs arising from implementing a given proposal at the ship level*". The relative threshold is estimated to be 50 $ per tonne and is the amount that shipping is expected to pay per tonne of carbon dioxide abated to *"help bridge the gap between the expected global baseline emissions in 2030 and the target emissions needed in order to limit temperature increase of 2 degrees C".* As one can understand this threshold is based on the high uncertainties involved with the mechanisms, costs and benefits to achieve the "2 degrees C guardrail", therefore this value may not be appropriate and has to be further analyzed.

4. Conclusions

Ship air emissions are at the center stage of discussion by the world shipping community and environmental organizations. These gases are responsible for climate change that could endanger future well being of humans and the ecosystem, although there is uncertainty about the scale and the timing of these effects. Measures to curb future CO_2 and other GHG growth are, therefore, being sought with a high sense of urgency.

It is a necessity, not to mention that in some countries it is required by the law, to be able to measure the damage that is caused or the benefit to the society from averting emissions. In order to do so, a monetary value has be placed by using a per mass price to these emissions –

that is the carbon cost. The paper has examined the major different approaches that are used in order to arrive at such a figure. It should be stressed once again that this figure is not common among different agencies. The purpose of this paper was to present these different valuation methods and to present the used of such figures in risk assessments and policy analysis frameworks such as cost-benefit and cost-effectiveness analysis. Finally we emphasize that further research has to be done in order to determine an appropriate value to be used in shipping.

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