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COMMITTEE IV.1

DESIGN PRINCIPLES AND CRITERIA

COMMITTEE MANDATE

Concern for the general concept of goal orientated design, for the quantification of general sustainability aspects in economic, human and environmental terms and for the development of appropriate procedures for rational life-cycle design of marine structures. Special attention shall be given to the issue of GBS as presently implemented within IMO. Possible differences between the current regulatory framework for ship structures and the design requirements developed for offshore and other marine industries shall be considered.

COMMITTEE MEMBERS

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KEYWORDS

Ship design principles, goal orientated design, design for sustainability, rational design criteria, internalization of costs, societal cost benefit analysis.

CONTENTS

1. INTRODUCTION

1.1 General concept of sustainability oriented design

The present report, as the previous ISSC reports of Committee IV.1, follows the same general definition of sustainability that was given by the Brundtland Commission of the United Nations: "economic development which meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (UN-WECD, 1987).

A sustainable development of the maritime transport involves therefore a detailed consideration of all the negative implications such transport mode has for the human society (social costs) and a proper assessment of compliance to the general sustainability target, based on a cost/benefit analysis.

As stated by Korzhenevych et al. (2014), transportation contributes significantly to economic growth and enables a global market. Transport modes, however, also produce negative effects. Shipping traffic, in particular, contributes to air and water pollution and shipping accidents to losses in terms of human lives, economical losses and ecological damages. These effects give rise to costs that can be expressed in monetary terms and affect in various ways the Society: health costs caused by air pollution (due to NO_x, SO_x, PM, …), lives lost and loss of biodiversity in traffic accidents, costs related to the world scale climate impact of shipping, etc.

These societal costs are referred to as external costs, that sum up to those directly borne by the transport first and second parties (private or internal costs, such as: wear, tear and energy cost due the ship operation, own time costs, transport fares and transport taxes and charges (port fees, pilot, insurance, etc.). The same kind of classification applies to benefits: first and second parties take advantage of most of them, even though society also experiences a gain.

The external costs of transportation are generally not paid by transport actors and hence not taken into account when they take a decision about a transport activity.

Internalisation of external costs means making such effects part of the decision making process of transport first actors. This can be done directly through regulation, i.e. issuing specific requirements in terms of operational and/or design control measures, or indirectly, providing suitable incentives to transporters with market-based instruments (e.g. taxes, charges, emission trading, etc.). Combinations of these basic types are also possible.

In other terms, the role of the Regulator is to assess if and under which conditions a transport activity is acceptable from a Societal viewpoint and to establish a Regulatory Framework able to control the societal losses and redistribute their costs in a balanced way, in particular on the first actors of the transportation process (internalisation of the external costs). In a technical analysis of sustainability, it is important that all external costs are included. All kinds of costs incurred during the lifetime of the product must be assessed. Additionally, some social costs are incurred also long after the product lifetime has expired, as is the case for the CO_2 emitted during the lifetime of the product. It is also important to include external costs of all raw materials that goes into the product, like e.g. the steel used to construct a ship. In a comparison of sustainability of e.g. different transport mode, it is also important to properly account for the differences in tax regimes.

The key point of this concept is a proper evaluation of the external costs, (also called social or implied costs) that are now not directly perceived as such by the actors.

This means, in a first place, the identification of all implications (negative and, in case, positive) of the transportation process and a quantification on a monetary scale.

The results of this type of investigations that has been carried out by different research groups will be reviewed and commented in chapter 2 with reference to the shipping sector.

1.2 Goal oriented normative framework

Another issue for the Regulator when establishing a regulatory framework is the way the various requirements are organized internally. Such requirements can regard subjects of different degrees of detail and targets of different levels of generality. A trend in the definition of the worldwide shipping regulatory framework at the international Maritime Organisation (IMO) in the last decade has been to organize the targets of the regulatory action in hierarchical order (from an upper level, the most general, to the most detailed ones, corresponding to the provisions on specific items of the ship). The procedure has a qualified characteristics in the internal coherence of the various levels, which is to be checked by codified procedures. This verification process in particular is applied to check the correspondence of the lower level requirements (Classification Societies Rules and Standards) to the upper level targets (goals and functional requirements).

This approach has been named in the maritime field ‘Goal Based’ and the first applications have been reviewed in the past reports of this committee, while a few recent ones will be considered in chapter 5.

Without recalling in details these applications, it is here noted that different results can be obtained depending on the way the requirements at the higher levels are formulated and on the way the coherence between levels is assessed.

1.3 Procedures for the impact analysis of regulations

The study of the impact of normative requirements to assess their acceptability from a societal point of view has been carried out by different Regulatory Bodies under different terms and in different ways, generally focussing on specific aspects of the impact.

At OECD level, these investigations have been termed Regulatory Impact Assessment (RIA), which, also from a semantic viewpoint, does not set boundaries to the evaluation of the regulation impact (neither in the type, nor in the domain of the impact). “RIA has been conceived as a key instrument for improving regulatory quality and good governance by ensuring more coherent and transparent policies and for making regulation more effective and efficient. By analysing potential consequences of proposed regulations, and by comparing different options, RIA is a methodological framework and an administrative procedure for better-informed policy-making. If properly conducted, the impact assessment should systematically assess the impact likely to arise from government regulation and communicate this information to the decision-makers” (Jacob et al., 2011).

The generic statement above reported about the necessity in a RIA of a systematic assessment of all types of impacts arising from the regulation to be evaluated has found an increasingly broader interpretation with time at OECD. Following again (Jacob et al., 2011) and related bibliography “Originally, RIA focused on identifying the direct economic costs and benefits of different regulatory alternatives on a wide range of actors, see (Kirkpatrick and Parker, 2007), (Radaelli and De Francesco, 2010). But in recent years RIA has experienced a high degree of diversification of approaches regarding orientation, ambition, institutionalisation and transparency of the procedures. Nowadays, in several countries, RIA requires the assessment of all types of possible impacts. It varies among countries, however, to what extent these assessments comprise a consideration of environmental issues”.

In other contexts than OECD, the impact assessment has been focussed specifically on environmental aspects, (Life Cycle Assessment (LCA) of a manufact or an activity), but in this case the analysis is limited to regular emissions: see, in particular for ships, e.g.: (Mountaneas et al., 2015).

On the other hand, as mention above, at IMO impact evaluations concentrated so far on safety, following the FSA procedure and focussing on low probability accidental consequences for humans.

A possibility, which has not been yet enforced in the maritime field and is here proposed for future applications, is to set the sustainability of the ship transport system as top goal for the normative framework of shipping. This implies (in a Goal Based-structured perspective) to verify the functional requirements at the second level in terms of a regulatory impact assessment based on a sustainability evaluation, accounting for all internal and external costs. This is very well in line with the general trend above recalled towards a generalisation of the impact concept in a regulatory context.

It is here noted that, from this viewpoint, the term sustainability assumes an holistic meaning (wider than in other contexts). Its definition expands in space, in time (to intra-generational periods) and in the probability domain (from regular to very rare events), in order to include all possible types of impacts.

In this respect, the influence of the emissions of a ship on the global climate changes on a planetary scale, as well as the life cycle impact of the ship on future generations and the expected values of the damages caused to humans, property and bio-diversity by rare accidental events are all possible examples of aspects to be included in the impact assessment.

2. QUANTIFICATION OF SUSTAINABILITY ASPECTS

In this chapter, measurement and assessment criteria regarding to various aspects included in the sustainability concept are presented. In particular several approaches developed for internalizing costs associated to assets, loss of human life, human injures, oil spills and environmental pollution are reviewed. This allows the inclusion of sustainability-related costs into cost benefit/effectiveness analyses and therefore in a rational decision-making process.

2.1 Economic aspects

In the context of a cost benefit analysis carried out from a societal viewpoint, the cost of a human activity (e.g. a transport mode) represents the effort the society is called to pay in order to implement that activity. Such cost should be balanced by a societal gain.

In a broad sense, the cost includes all types of negative effects the activity implies. The economic burden of an activity is part of this picture, perhaps the most evident and studied one, at least for the part internal to first parties of the process. Expenses for designing, building, running, maintaining, repairing and dismantling a ship are all examples of resources devoted to a maritime transport mode. Some of the expenses may be deterministically defined, other are affected by uncertainties (e.g. fuel consumption, in dependence of weather conditions) or need to treat in a probabilistic way (accidents).

Also in case of the economic items of the balance, however, it is important to include all aspects in the analysis. With reference again to Korzhenevych et al. (2014) it is here recalled that the societal costs for a generic transportation mode should include on the long term also the building costs for re-building and or adapting to new requirements the infrastructures needed for the particular transportation mode. This in addition to the maintenance costs for the existing infrastructure that are definitely included in the external costs. In the specific case of shipping, this item relates f.i. to the construction of new ports, in addition to the dredging, maintenance, and service costs related to the normal functioning of ports

2.2 Human aspects

In this section it is covered how is it possible to account for the aspects related to the safety (life, health and well being) of humans in the context of (normative) decision making.Indicators (indexes) and criteria for the assessment will be reviewed.

2.3 GCAF and NCAF indicators for loss of life

Indicators based on a cost-effectiveness ratio related to the safety of human life are available in the maritime industry since some time (Norway, 2000) and have been formally accepted by including them into the consolidated FSA guidelines (IMO, 2007) and later into their revised version (IMO, 2013b). The implication is that internalizing costs related to safety, injuries and ill health in any decision model becomes possible.

Indicators used to express the cost effectiveness of risk control measures are the Gross and Net Cost of Averting a Fatality (GCAF/NCAF), as described in Appendix 7 of the FSA Guidelines (IMO, 2013b).

<u>Definition</u>
The Gross Cost of Averting a Fatality (GCAF) is defined in terms of ratio of marginal (additional) cost ΔC of the risk control option divided by the reduction in risk to personnel in terms of the fatalities averted ΔR; i.e.:

$$GCAF = \frac{\Delta C}{\Delta R} \tag{1}$$

The Net Cost of Averting a Fatality (NCAF) index is defined by subtracting possible economic benefits ΔB of the risk control option (e.g benefits deriving from the reduction in economic lossess and environmental damages that is expected by implementing the safety measure) from the cost of the risk control option (RCO):

$$NCAF = \frac{\Delta C - \Delta B}{\Delta R} \tag{2}$$

According to appendix 7 of the revised FSA guidelines (IMO, 2013b), either the two indices can in principle be used. However, it is recommended to firstly consider GCAF and if the cost effectiveness of an RCO satisfies the inherent acceptance criterion (see below), then NCAF may be also considered. The reason is that NCAF may be misused in some cases for pushing certain RCOs, by including more categories of economic benefits when considering preferred RCOs.

NCAF and GCAF can always be adopted to compare different RCOs from the viewpoint of their cost-effectiveness.

<u>Assessment (acceptance criteria)</u>
For both the GCAF and the NCAF, appropriate cost-effectiveness criteria can be specified in terms of quantitative reference values for the maximum cost of averting a fatality. In other words, limit GCAF/NCAF values can be set, below which safety measures are to be considered cost-effective in an absolute way.

A criterion defined in terms of a limit value of GCAF/NCAF of US$ 3 million was suggested by (Norway, 2000) and this was the value provided by IMO (2007) for illustrative purposes (Table 1). According to IMO (2007) and later to IMO (2013b), specific values selected as appropriate should be explicitly defined and used in any FSA study.

Table 1. Cost-effectiveness criteria for NCAF and GCAF indicators ((IMO, 2007), (IMO, 2013b)).

	NCAF [US $]	*GCAF* [US $]
Criterion covering risk of fatality, injuries and ill health	3.0×10^6	3.0×10^6
Criterion covering only risk of fatality	1.5×10^6	1.5×10^6
Criterion covering risk of injuries and ill health	1.5×10^6	1.5×10^6

These criteria are not static and, on the contrary, should be updated every year according to the average risk free rate of return (see the discussion of rates in chapt. 3 below) or by calibrating the limit value on the basis of other indicators and inherent acceptance criteria (e.g the Life Quality Index criterion, see below).

The NCAF is a price which society should be willing to pay for saving lives according to its ethical principles and which society can afford, i.e. for safety-relevant regulations in cost-benefit calculations. Independently from the way its is found, the NCAF, however, should never be taken as the value of human life (Rackwitz, 2002b).

2.3.1 Life Quality Index

Definition

The Life Quality Index (LQI: see (UNDP, 1990), (Lind, 2002)) is a social indicator reflecting the length of a quality life in a given society.

It is constructed from two aggregated indicators, i.e. the life expectancy at birth (*e*) and the gross domestic product pro capite (*g*),

$$\mathrm{LQI} = g^{w}\, e^{(1-w)} \tag{3}$$

where the exponent *w* is the proportion of life spent in economic activity (*w*=1/8 in developed countries).

Acceptance criterion

Using the definition in Eq. 4, a Life Quality Index criterion ((Nathwani et al., 1997), (Skjong and Ronold, 1998), (Skjong and Ronold, 2002), (Rackwitz, 2002a), (Rackwitz, 2002b)) may be defined: according to such criterion, safety interventions are regarded as justifiable as long as they contribute positively to LQI. The improved safety by implementation of a safety measure is expressed through a positive change *Δe* in the life expectancy, *e*. The cost of implementing the measure is expressed through a change, *Δg* in the gross domestic product, *g*. The Life Quality Index Criterion implies that the measure is implemented when

$$\frac{\Delta e}{e} > -\frac{\Delta g}{g}\frac{w}{1-w} \tag{4}$$

which results from differentiation of the expression that defines the LQI and requiring a positive increment in the index: ΔLQI>0

The use of this criterion for decision-making on a particular normative option implies that one is willing to take on an increased risk, expressed in terms of a negative *Δe*, if the associated gain or compensation *Δg* is large enough. Optimality is achieved when the inequality of the Life Quality Index Criterion is turned into equality.

Assuming that saving a human life corresponds to saving, in years, half the life expectancy of an individual: *Δe*=*e*/2, the limit acceptable value for the net cost of averting a fatality, $(NCAF)_{acc}$, can then be calculated as:

$$\left(NCAF\right)_{acc} = \frac{g\,e}{4}\left(\frac{1-w}{w}\right) \tag{5}$$

The acceptable NCAF value of Eq. (6) can be updated from global statistics, available at the websites of OECD, CIA World Factbook, International Monetary Fund (IMF) and World Bank (WB). The OECD member countries are typically adopted to calculate average values of NCAF as they represent about 95% of the global GDP and presumably a similar share of the maritime transport. When updating the NCAF criterion all parameters can be revised (i.e. *g, e w*).

From these, the *g* (Gross National Product pro capite) is the one with larger variability, while the percentage of the lifetime spent in economic activity (*w*) is typically not easily obtained.

Figure 1 shows the variation on the average *NCAF* for the OECD countries from 1995 to 2011. Table 2 shows that the total average values of OECD countries in the period 2002-2011 is approximately 4.63×10^6 US$, which corresponds to an increase of 50% compared to the average of the period 1995-2005 (3.07×10^6 US$).The main changes are due to the fact that the number of OECD countries has increased, the pro capite Gross Domestic Product has increased, life expectancy at birth has increased and less time is spent in economic activity. In addition the US$ has decreased its value against most other currencies.

Table 2. Time variation of the average NCAF value of the OCDE member countries (10^6 US$).

Year	1995	2000	2005	2009	2012	1995-2005	1995-2011	2002-2011
NCAF	2.74	2.70	4.31	5.05	5.76	3.07	3.85	4.63

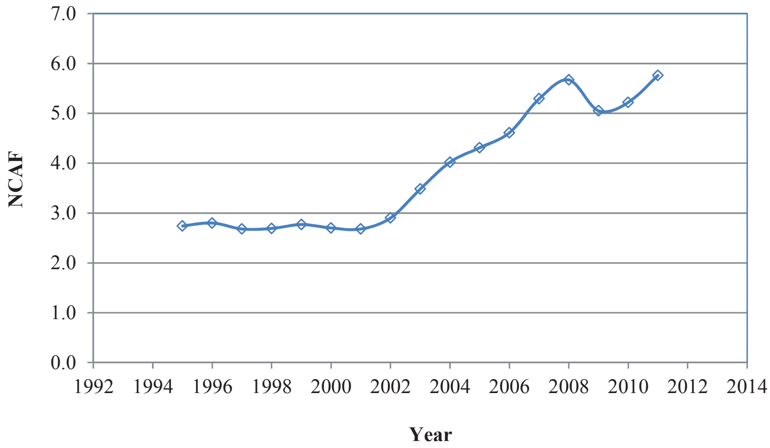

Figure 1. Variation of the average *NCAF* for the OCDE countries from 1995 to 2011 (Data source: OCDE statistics).

2.3.2 *DALY and QALY indicators*

For quantifying health effects and injuries, the FSA Guidelines advocate the use of the DALY (Disability Adjusted Life Years)/QALY (Quality Adjusted Life Years) concept, which is promoted by the World Health Organization (WHO).

<u>Definitions</u>

The disability-adjusted life year (DALY) is a measure of overall disease burden, expressed as the number of years lost due to ill-health, disability or early death.

The DALY was first conceptualised by Murray and Lopez in work carried out with the World Health Organization and the World Bank known as the global burden of disease study (Murray and Lopez, 1996).

The DALY is becoming increasingly common in the field of public health and health impact assessment (HIA). It “extends the concept of potential years of life lost due to premature death...to include equivalent years of ‘healthy’ life lost by virtue of being in states of poor health or disability”. In so doing, mortality and morbidity are combined into a single, common metric.

Traditionally, health liabilities were expressed using one measure: (expected or average number of) ‘Years of Life Lost’ (YLL). This measure does not take the impact of disability into account, which can be expressed by: ‘Years Lived with Disability’ (YLD). DALYs are calculated by taking the sum of these two components. In a formula:

$$\text{DALY} = \text{YLL} + \text{YLD} \tag{6}$$

The DALY relies on an acceptance that the most appropriate measure of the effects of chronic illness is time, both time lost due to premature death and time spent disabled by disease. One DALY, therefore, is equal to one year of healthy life lost.

The quality-adjusted life year or quality-adjusted life-year (QALY) is a measure of disease burden, including both the quality and the quantity of life lived. The QALY was originally developed as a measure of health effectiveness for cost-effectiveness analysis, a method intended to aid decision-makers charged with allocating scarce resources across competing health-care programs (Fanshel and Bush, 1970; Torrance et al., 1972; Weinstein and Stason, 1977).

The QALY is based on the number of years of life that would be added by the intervention. Each year in perfect health is assigned the value of 1.0 down to a value of 0.0 for being dead. If the extra years would not be lived in full health, for example if the patient would lose a limb, or be blind or have to use a wheelchair, then the extra life-years are given a value between 0 and 1 to account for this.

Acceptance criteria

A possible way to develop an acceptance criterion based on the DALY concept, i.e. to define an acceptable cost for averting a loss (or obtaining the gain) of 1 year of healthy life, is to derive such criterion from the NCAF criterion (see sect. 0 above). This can be obtained by assuming that one prevented fatality implies 35 (i.e. $e/2$ (where e is the life expectancy) Quality Adjusted Life Years gained. i.e.:

$$\left(\text{Cost for averting a loss of 1 year of healthy life}\right)_{\text{acc}} = \frac{\text{NCAF}_{\text{acc}} / 2}{e} \tag{7}$$

which, assuming for the acceptable NCAF a value of $3 \cdot 10^6$ US$, provides an acceptable cost per DALY gained of 42000 US$.

Although the DALY criterion may have some limitations and more research on this is required, the criterion may be sufficient in prioritizing risk control options. It is surprising how the value of US$42000 is close to other criteria derived by different techniques such as the one used for decisions in the health care sector, where e.g. Gafni (1999) refer to a DALY of $35,000. Also, the average value for life saving interventions in the US in (Tengs et al., 1995) is also $42.000 per life-year (Skjong, 2009).

In any case both the CAF and DALY/QALY Criteria can be regulary updated based on the LQI formulas above. One of the lhe latest updates was carried out in (Spouge and Skjong, 2014).

2.4 Environmental aspects

In this section, indicators for quantifying some of the environmental consequences of a normative decision will be discussed.

2.4.1 Cost of averting a tonne of oil spilt (CATS)

A cost effectiveness criterion related to accidental oil spills of tankers has been suggested by Vanem et al. (2008) based on the work performed under the EU project SAFEDOR. Vanem et al. (2008) have proposed an evaluation criteria based on cost effectiveness considerations, i.e. the cost of averting a tonne of oil spilt (CATS). The rationale behind the approach suggested is in line with cost effectiveness criteria normally employed in Formal Safety Assessment (FSA) studies on safety issues, i.e. the GCAF/NCAF (Gross/Net Cost of Averting a Fatality). Based on a review of available oil spill statistics and a generic, global average cost per tonne of oil spilt, Vanem et al. (2008) have formulated a criterion in terms of CATS, suggesting that options with a CATS value less than $F \times$ $40,000 should be implemented. An exact value for the assurance factor F was not established, but it was indicated that it should take a value between 1 and some upper limit of 3. This work has also compared the proposed criteria with previous actual decisions related to the OPA 90 regulations. Overall, it was found that the proposed methodology is in general agreement with previous decisions and that the suite of OPA regulations corresponds to a CATS value of approximately USD 63,000 showing that the proposed CATS criteria are appropriate and the overall OPA 90 regulations are sensible and associated with a reasonable degree of cost effectiveness. This would correspond to an assurance factor F of 1.5 for the global criterion, and would also be in agreement with previous decisions. However, Vanem et al. (2008) recommended that further studies should be carried out in order to obtain more accurate estimates of oil spill costs, but until better statistics become available, the CATS value of $60,000 (1.5 × $40,000) could be adopted.

A debate led by Greece has also started at the 56th MEPC (Greece, 2007), focusing on the formulation and the value of CATS, alerting for the extreme variability of the per tonne cost (clean-up and damage) of oil spills worldwide. Furthermore, the document stated that the use of a single criterion focused on the volume of oil spilt was not sufficient, given that, from the multiple variables that influence this cost, volume is not the most relevant. MEPC 56 had therefore agreed to establish a correspondence group, under the coordination of Greece to carry out an in-depth analysis of the proposed environmental risk evaluation criteria for the purpose of the Formal Safety Assessment (FSA) before inclusion of such criteria in the IMO FSA Guidelines.

At MEPC 60 (March 2010), after considerable debate, the majority of the members of the Working Group on Environmental Risk Evaluation Criteria within the context of Formal Safety Assessment expressed its preference for a non-linear approach instead of a constant CATS threshold. To this effect, MEPC 60 agreed that in order to arrive at the recommended CATS criterion, the following should be considered, among other things (IMO, 2010), *MEPC 60/WP.11*):

(1) Member governments or interested organizations having their own additional data attempt to verify, and adjust as necessary, the said regression formula by incorporating their additional (chosen) data in the analysis. In this connection, MEPC 60 agreed to invite the interested stakeholders to submit their data for each cost component and the results of their analysis for consideration.
(2) Following a more reliable establishment of the cost curve, a proposed CATS formula, to be used in the cost-effectiveness step of FSA can be established by introducing a margin or factor value (so-called assurance factor), still to be agreed, representing society's willingness to prevent an accident rather than to simply neutralize its consequences.
(3) MEPC 60 invited member governments and interested organizations to use the non-linear cost function in FSA studies with a view to gain experience with its application and provide information to the IMO which may help to improve the proposed functions.

In the meantime several studies had been performed to quantify the total cost of an oil spill using different regression approaches and different sources of data, as reviewed by Kontovas et al. (2010).

Shahriari and Frost (2008) proposed a mathematical method for estimating clean up costs based on regression analysis of 80 incidents occurred during the period 1967–2002. The model's parameters included the quantity of oil spilled, the oil density, the distance to shore, cloudiness and level of readiness based on ITOPF estimations on how well different world regions cope with oil spills. Liu et al. (2009) proposed a log linear relation between the total cost and the spill size based on a combination of simulating and estimation methods.

Yamada (2009) performed a regression analysis of the quantity of oil spilled and the total cost of the spill using data from the Annual Report from the IOPCF (International Oil Pollution Compensation Fund). The study of Yamada (2009) was officially submitted by Japan to IMO MEPC recommending a volume based approach to quantify the total cost of oil spills (Japan, 2008), *MEPC 58/17/1*) given by the regression formula:

$$C = \mathrm{f}(V) = 38{,}735 V^{0.66} \tag{7}$$

where C is the total spill cost in US % and V the spill size in tonnes.

Psarros et al. (2011) have analysed cost data for 185 oil spill incidents combining the IOPCF data with spill data derived from the accident database developed during the EU Research SAFECO II and proposed a value of \$80,000/tonne, as a CATS criterion. This value was achieved using an assurance factor of 1.5 and the mean total cost value of \$54,721/tonne (i.e. E(C/V), where C is the total spill cost and V the spill size in tonnes). Psarros et al. (2011) have also obtained a regression model to estimate the total unit cost of an oil spill as a function of the amount of oil spilled that is very similar to that of document MEPC 59/INF. 21 submitted by Norway (2009) to MEPC 59 in July 2009 as

$$C = \mathrm{f}(V) = \frac{60{,}515}{V^{0.353}} = 60{,}515\, V^{0.647} \tag{8}$$

The mean total cost value of \$54,721/tonne and the corresponding CATS value of \$80,000 have been criticised by Psaraftis (2011), as the \$54,721/tonne do not correspond to the average of the ratio "spill cost/spill volume (*C/V*)" but to 93th percentile of the distribution of the ratio *C/V*. According to Psaraftis (2011), the \$54,721/tonne value can lead to erroneous results, particularly when extrapolated and applied to all spill sizes. Therefore, a better option would be to use the non-linear function that relates spill cost (C) and spill volume (V) instead of linearizing it or even approximating it as, C= \$54,721 V.

Kontovas et al. (2010) have reviewed some previous studies and have also performed a regression analysis of oil spill cost data provided by the IOPCF. The dataset used to estimate the total cost of oil spills consisted of 83 spills in the period 1979-2006 obtained after removing incomplete entries and outliers. The minimum volume was 0.1 tonnes and the maximum was 84,000 tonnes. The average spill was 4854.29 tonnes but the median was just 140 tonnes, which clearly show that most claims came from relatively small spills. In fact, only 11 spills were above 5000 tonnes and, thus, one should be very careful when using the regression formulas to extrapolate the cost of large spills. Using this dataset Kontovas et al. (2010) have proposed the following non-linear function of total spill cost versus spill weight that has been also submitted by Greece (2009) as MEPC 60/17, annex 2:

$$C = \mathrm{f}(V) = 51{,}432\ V^{0.728} \tag{9}$$

The Working Group on Environmental Risk Evaluation Criteria at MEPC 60 noted that the research work independently conducted by Japan (2008) (MEPC 58/17/1), Norway (2009) (MEPC 59/INF.21) and Greece (2009) (MEPC 60/17, annex 2) summarised in Table 3 led to very similar non-linear regression functions of total spill cost versus spill weight. Among these non-linear regressions models the one proposed by Greece was considered as more conservative, resulting in larger cost figures per tonne of oil spilled, except for spills less than 4 tonnes as illustrated in Figure 2 and was proposed as a basis for further analysis (IMO, 2010), *MEPC 60/WP.11*).

Table 3. Non-linear functions of total spill costs (obtained by regression) (IMO, 2010).

Reference	Total Spill Cost (C) in US \$ versus spill weight (V) in tonnes	Data Source
(Japan, 2008) (MEPC 58/17/1)	$38{,}735\ V^{0.66}$	IOPCF
(Norway, 2009) (MEPC 59/INF.21	$60{,}515\ V^{0.647}$	IOPCF, SAFECO II EU project
(Greece, 2009) (MEPC 60/17, annex 2)	$51{,}432\ V^{0.728}$	IOPCF

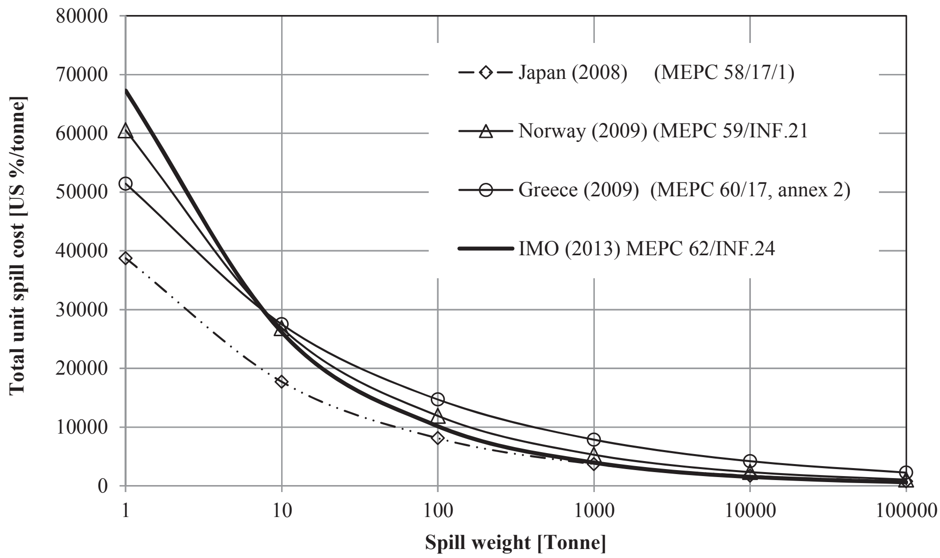

Figure 2. Total unit spill cost [US\$/tonne] versus spill weight for V≥1 tonne (IMO, 2010).

In July 2011 at the 62th MEPC (IMO, 2011c), *MEPC 62/WP.13*), the work on CATS was completed and a spill sized dependent formulation was agreed and included in the annex 7 of the revised IMO FSA Guidelines (IMO, 2013b). First, a consolidated oil spill database, developed jointly by Germany, Japan, Greece and the United States and based on IOPCF data, US Data and Norwegian data, was endorsed. Second, MEPC 62 agreed that the following volume-based total spill cost regression formulae derived from the consolidated oil spill database could be appropriate to be used in environmental FSA studies (Table 4).

Table 4. Volume-based total spill cost regression formulae (IMO, 2013b).

Dataset	C = f(V) = Total Spill Cost (TSC) [in 2009 US dollars]	Reference
All spills	$67{,}275\ V^{0.5893}$	MEPC 62/INF.24
V > 0.1 tonnes	$42{,}301\ V^{0.7233}$	MEPC 62/18

Figure 3 shows the data of the consolidated oil spill database in terms of specific costs per tonne spilled (figure 5 of document MEPC 62/INF.24). Further information with respect to the basis of the database can be found in document MEPC 62/INF.24. It should be acknowledged that the consolidated oil spill database has limitations and possible deficiencies. These are described in document MEPC 62/INF.24 and may also involve incomplete or missing data on costs or other information.

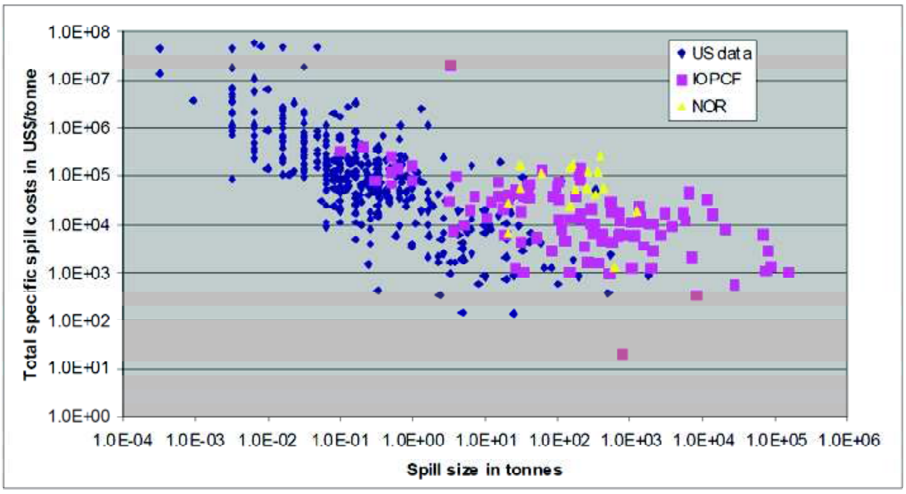

Figure 3. Oil spill costs as a function of spill size. All specific oil spill cost data in 2009 US$ (spill cost per tonne). Source: document MEPC 62/INF.24.

It is interesting to note (and quite unexpected) that even though data from the USA and Norway were added (and these are quite expensive spills), the new total spill cost functions obtained are well below the ones proposed by Greece, based on IOPCF data alone, and by Norway, based on IOPCF and data from the SAFECO EU project, for spills larger than 10 tonne, as shown in Figure 2.

Although the regression formulae of Table 4 derived from the consolidated database were suggested in the revised FSA guidelines (IMO, 2013b), the submitter of the FSA can amend this database with new oil spill data and is free to use other formulae, as long as these are well documented. For example, if a FSA is considering only small spills, the submitter may filter the data and perform his or her own regression analysis, however, this amendment should be properly documented.

It is recommended that the FSA analyst use the following formula to estimate the societal oil spill costs (SC) used in the analysis:

$$SC_{threshold} = F_{assurance} * F_{uncertainty} * f(V) \quad (10)$$

where $F_{Assurance}$ is assurance factor (allowing for society's willingness to pay to averting accidents), $F_{Uncertainty}$ is the uncertainty factor (allowing for uncertainties in the cost information from occurred spill accidents, and f(V) is the volume-dependent total cost function representing the fact that the cost per unit oil spilled decreases with the spill size in US$ per tonne oil spilled.

According to IMO (2013b), the values of both assurance and uncertainty factors should be well documented. In addition, if value of $F_{Assurance}$ and $F_{Uncertainty}$ other than 1.0 are used, a cost-effective analysis using $F_{Assurance}$= 1.0 and $F_{Uncertainty}$ = 1.0 should be included in the FSA results, for reference. In order to consider the large scatter, the FSA analyst may perform a regression to determine a function f(V) that covers a percentile different than 50 % and document it in the report.

Psaraftis (2012) identified some open issues on this topic that are related to the considerable options that the amended FSA guidelines provide to the FSA analyst when performing an environmental FSA. These are mainly related to the selection of both assurance and uncertainty factors and the possibility to perform a regression analysis not at 50 % (as is standard in all regressions), but at a level different from (and likely higher than) 50 %. For instance, there has been no agreement on the specific value for the assurance factor, even though there is a clear belief by some IMO delegations that this factor should be well above 1.0. On the other hand, some other delegations have suggested that this factor should not be the object of an FSA study but should be left for policy makers to decide. As things stand, the value of this factor is open, and FSA allows any value, so long as it can be well documented.

Also, it is not clear how the uncertainty factor can be calculated with a reasonable degree of confidence. In fact, as spill claims are typically inflated, the uncertainty factor can even be less than 1.0, but some IMO delegations want to use an uncertainty factor much higher than 1.0 (Psaraftis, 2012). As things stand, any uncertainty factor can be used in an environmental FSA, as long as it is well documented.

It is still unclear if the present formulations will be corresponding to the willingness to pay for averting oil pollution accidents that are implicit in the present MARPOL. An agreement at IMO on how to internalize the societal cost of oil spill in the regulatory process, is anyway important for the 'design for sustainability approach' (Skjong, 2009). This may be compared to the decision processes in EU on offshore regulations. The EU Impact Assessment (EU, 2011) is largely a worst case scenario analysis estimating a return period for a Macondo type accident in Europe.

2.4.2 CO_2 emissions costs

A Cost of Averting a Tonne of CO_2-eq Heating (CATCH) criterion was proposed by (Skjong, 2009). The methodology proposed is in line with the analysis carried out by Intergovernmental Panel on Climate Change (IPCC) presented in the Fourth Assessment Report, in the contribution from Working Group III (IPCC, 2007a). The report contains estimates of the risk reduction at different carbon price levels, both based on top-down and bottom-up studies and for two different scenarios, reproduced here in Table 5 and Table 6 (Skjong, 2009).

Eide et al. (2009) applied the methodology for assessing the cost-effectiveness of technical and operational measures for reducing CO_2 emissions from shipping, through the development of the evaluation parameter called the CATCH and a decision criterion for the implementation of measures, against which the evaluation parameter should be evaluated. The decision parameter for emission reduction CATCH has been established using the same approach adopted in the development of the decision parameter, *NCAF* (Net Cost of Averting a Fatality), already included in the FSA guidelines (IMO, 2007, IMO, 2013b), and the similar parameter for assessing measures for oil spill reduction, CATS (Cost of Averting a Tonne of oil Spill): see Vanem et al. (2008); Skjong et al. (2005); (Skjong, 2009).

Table 5. Global economic mitigation potential in 2030 estimated from bottom-up studies.

Carbon Price (US$/t$CO_2$–eq)	Economic Potential (GtCO_2 –eq/yr)	Reduction Relative to SPES A1B (68 GtCO_2 –eq/yr) (%)	Reduction Relative to SPES B2 (49 GtCO_2 –eq/yr) (%)
0	5-7	7-10	10-14
20	9-17	14-25	19-35
50	13-26	20-38	27-52
100	16-31	23-46	32-63

Table 6. Global economic mitigation potential in 2030 estimated from top-down studies.

Carbon Price (US$/t$CO_2$–eq)	Economic Potential (GtCO_2 –eq/yr)	Reduction Relative to SPES A1 B (68 GtCO_2 –eq/yr) (%)	Reduction Relative to SPES B2 (49 GtCO_2 –eq/yr) (%)
20	9-18	13-27	18-37
50	14-23	21-34	29-47
100	17-26	24-38	35-53

The economic potential for emission reduction estimates is surprisingly consistent at all carbon price levels, (Skjong, 2009). Two scenarios are defined as follows: the A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in pro capite income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).

The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

Assuming that the politically expressed wish to reduce the emission by 80%, compared to the current level B2 scenario at 2030, and ignoring the uncertainties, this indicates that all measures that can avert a tonne of CO_2 –eq emission for less than or about \$50 should be implemented now or in the near future. This is higher than the current price in e.g. the EU market and demonstrates that the current market based instrument fail to internalize the societal costs. At IMO this way of deciding to implement RCOs would be consistent with current decision making processes and FSA, e.g.

$$(\text{CATCH})_{acc} = \text{acceptable Cost of Averting a Tonne } CO_2 \text{ –eq Heating effect} = \$50 \qquad (11)$$

It may obviously also be argued that due to the uncertainty in the estimates, and the long term irreversible effect of climate change, a safety factor should be introduced too. For EU and others, a reference to the precautionary approach would be of relevance, as this is also representing an agreed policy.

Using CATCH < 50 USD/tonne as an acceptance criterion ensures that shipping contributes to the reduction in GHG emissions in a way that is cost-effective and complies with the (IPCC, 2007a) recommendations. On the other hand, depending on the cost of reducing emissions caused by shipping, this criterion cannot be used to achieve a specific amount of reduction. Again, this is in agreement with both the IPCC way of thinking and the Kyoto protocol (UNFCCC, 1997), the only difference between these two being that the trading mechanisms established under the Kyoto protocol assume that the CATCH is established by market mechanisms and the trading of CO_2 quotas, whereas the IPCC uses a specific concentration target and analyses the cost of reducing the CO_2 level to that amount.

The suggested CATCH <50\$/T CO_2-eq has been used as a decision criterion for investment in GHG emission reduction measures for shipping. Eide et al. (2009) have analysed a number of specific technical and operational measures for reducing CO_2 emissions for selected ships showing that several measures are cost effective according to the proposed criterion. Assuming independence between the measures, the cost effective measures (not including speed reduction) considered by Eide et al. (2009) add up to an emission reduction in the order of 30% for the bulk carrier, and 40% for the container vessel.

The CATCH concept has been also applied by Longva et al. (2010a) for setting the target Energy Efficiency Design Index (EEDI), but could be used in various ways, including introducing a fuel levy. The approach quantifies the cost of averting greenhouse gas emission, which indicate the costs that needs to be internalized in the decision processes, by regulators and individuals to achieve sustainability.

2.4.3 Other emissions costs

Generally, there are two methods of estimating external costs of transport: bottom-up and top-down approaches (Essen et al., 2007) (Friedrich and Bickel, 2001). The bottom-up approach begins at the micro-level, in which basic elements are initially specified in detail and then connected to form a complete system. Hence, this approach is more precise with a potential for differentiation and is more suited to deriving marginal external costs. By contrast, a top-down approach operates at the macro-level, e.g., external costs of a country can be calculated and divided by the national transport volume, leading to average external costs. This method is easier to manipulate, but fails to incorporate specific details (Bickel and Friedrich, 2005). The above approaches have been widely used in many studies for evaluating air pollution effects, including ExternE (Bickel and Friedrich, 2005), UNITE (Tervonen et al., 2002) and (Nash, 2003), CAFÉ (Holland et al., 2005) , HEATCO (Bickel et al., 2006), RECODIT (Black et al., 2003), and GRACE (Nash et al., 2008), as reviewed by Jiang et al. (2014) in the context of the analysis of the costs and benefits of reduction measures for the shipping industry to comply with the forthcoming sulphur emission regulations.

Although the estimation of external costs has to consider several uncertainties, there is a wide consensus on the best approach. The state-of-the-art is the damage cost approach or the dose-response method (bottom-up approach). However, for assessing external costs of carbon emission, the avoidance cost approach (which evaluates the cost of achieving a given amount of emissions reduction) is typically used (Korzhenevych et al., 2014). The dose-response method focuses on the quantification of the explicit impact that the emissions have on human health, environment, economic activity, etc. Efforts undertaken in the last 20 years to develop standardised approaches involve a detailed analysis of the long chain of events preceding the final impact on the exposed population. The EU funded series of projects ExternE (Bickel and Friedrich, 2005) formalised this solution under the title *Impact Pathway Approach* (*IPA*) (Figure 4). IPA starts with from the quantification of the pollutant emissions to the determination of impacts and subsequently to the quantification of economic damage in monetary terms often based on valuation studies assessing e.g. the willingness to pay for reduced health risks, (Korzhenevych et al., 2014).

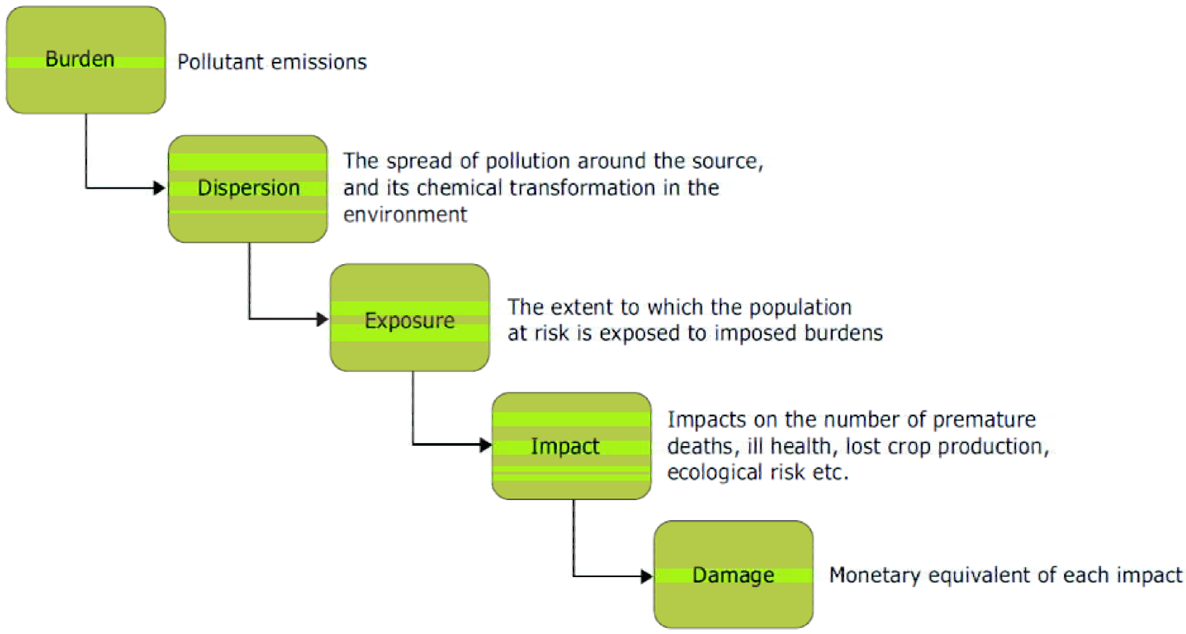

Figure 4. The Impact Pathway Approach (IPA) (EEA, 2011).

Recently, Korzhenevych et al. (2014) provided a comprehensive overview of the approaches for estimating external costs of transport, including air pollution cost from shipping, and recommend a set of methods and default values for use when conceiving and implementing transport pricing policy and schemes. This handbook on the external cost estimation updates the 2008 Handbook (Maibach et al., 2008) with new developments and data generated from research projects and scientific papers in Europe.

In particular for air pollution costs, Korzhenevych et al. (2014) report more recent damage costs from the NEEDS project (Preiss et al., 2008). In addition to covering all major pollutants and all Member States, the values provided in NEEDS have several features that are especially relevant for the purpose of policy application. First, they cover all European sea territories (very relevant for correctly calculating the external costs of maritime transport). Second, they cover not only health effects (that surely correspond to over 90% of the total external effect), but also quantify the side effects of emitted NOx and SO2 on materials (e.g. buildings), biodiversity, and crops. Table 7 reports cost values for all major pollutants calculated for all European sea regions using the EcoSense model (Preiss and Klotz, 2007) in the NEEDS project, updated to the price level of 2010.

Table 7. Damage costs of main pollutants in sea areas, in € per tonne (2010).

Sea region	NMVOC	NOx	PM2.5	SO2
Baltic Sea	1100	4700	13800	5250
Black Sea	500	4200	22550	7950
Mediterranean Sea	750	1850	18500	6700
North Sea	2100	5950	25800	7600
Remaining North-East Atlantic	700	2250	5550	2900

Source: NEEDS (Preiss et al. 2008), updated to year 2010 using EU nominal pro capite GDP (PPP) figures. All values are rounded.

Table 8 and Table 9 report unit cost values for maritime transport. The types of vessels and the corresponding emission factors are taken from (den Boer et al., 2011). It is important to note that some important vessel categories are not included (e.g. Ro-Ro, container ships due to a lack of comprehensive data in a consistent format. The damage costs presented below are differentiated by sea area according to damage costs reported in Table 7.

Table 8. Marginal air pollution costs (2010) for maritime transport (average load), EU average, € per 1000 tkm.

Type of ship	Average load, tonnes	Marginal air pollution cost, € per 1000 tkm				
		Baltic Sea	Black Sea	Mediterranean Sea	North Sea	Remaining North-East Atlantic
Crude oil tanker 0-10 kt	1761	4.94	5.22	3.02	6.70	2.37
Crude oil tanker 10-60 kt	18413	1.45	1.55	0.91	1.99	0.70
Crude oil tanker 80-120 kt	49633	0.95	1.01	0.59	1.29	0.45
Products tanker 0-5 kt	810	6.71	7.07	4.09	9.09	3.22
Products tanker 5-10 kt	3150	4.36	4.59	2.65	5.91	2.09
General Cargo 0-5 kt	1527	2.57	2.73	1.59	3.49	1.23
General Cargo 5-10 kt	4174	2.90	3.08	1.81	3.94	1.39
Bulk carrier (feeder)	1440	4.71	5.01	2.93	6.41	2.26
Bulk c. (handysize)	14300	1.39	1.48	0.87	1.89	0.67
Bulk c (handymax)	24750	1.01	1.08	0.63	1.38	0.48

Source: own calculations using emission factors from (den Boer et al., 2011). Damage cost factors (non-urban) from Table 7.

Table 9. Marginal air pollution costs (2010) for maritime transport (average load), EU average, € per ship-km.

Type of ship	Average load, tonnes	Marginal air pollution cost, € per ship-km				
		Baltic Sea	Black Sea	Mediterranean Sea	North Sea	Remaining North-East Atlantic
Crude oil tanker 0-10 kt	1761	8.70	9.19	5.33	11.81	4.17
Crude oil tanker 10-60 kt	18413	26.78	28.60	16.83	36.55	12.83
Crude oil tanker 80-120 kt	49633	46.93	50.03	29.38	63.98	22.49
Products tanker 0-5 kt	810	5.43	5.72	3.31	7.37	2.61
Products tanker 5-10 kt	3150	13.73	14.45	8.35	18.63	6.57
General Cargo 0-5 kt	1527	3.92	4.16	2.43	5.33	1.88
General Cargo 5-10 kt	4174	12.09	12.87	7.55	16.46	5.79
Bulk carrier (feeder)	1440	6.78	7.21	4.22	9.23	3.25
Bulk carrier (handysize)	14300	19.86	21.18	12.44	27.06	9.52
Bulk carrier (handymax)	24750	25.03	26.72	15.71	34.14	12.00

Source: own calculations using emission factors from (den Boer et al., 2011). Damage cost factors (non-urban) from Table 7.

3. DEPRECIATION RATES IN DECISION MAKING

In chapter 2 above a review has been presented of different items that should be taken into account for internalisation of the costs of transportation in general and of maritime transportation in particular. Costs and benefits, however, occur at different positions along the time axis. This raises the key question of how to compare these elements i.e. how to account for the dependence on time of the utility function.

The concept of time-dependence of the utility function in decision making was introduced by Samuelson (1937) when proposing the discounted-utility (DU) model. Despite Samuelson's clear reservations about the normative and descriptive validity of the model he had proposed, the DU was accepted instantly, not only as a valid normative standard for public policies (e.g., in cost-benefit and cost-effectiveness analyses), but as a descriptively accurate representation of actual behaviour.

A key assumption of the DU model is that all of the disparate motives underlying inter temporal choice can be condensed into the discount rate.

It is important, however, to distinguish among the varied considerations that underlie inter temporal choices and to distinguish 'time discounting' from 'time preference'. The first broadly is to encompass any reason for caring less about a future consequence, including factors that diminish the expected utility generated by a future consequence, such as uncertainty or changing preferences. The second term refers, more specifically, to the preference for consumption now over delayed consumption. Shane et al. (2002) demonstrates that many of the studies to reveal time preferences are actually masked by other reasons for discounting.

3.1 Pure time preferences

Pure time preferences reflect individuals' preference for consumption now, rather than later, and are a central element in economic models used in policy recommendations related to sustainability and climate change.

Shane et al. (2002) carried out a rather detailed review of the background for discounting pure time preferences. The paper demonstrates that economists working on this item have been predominantly focused on people's perception of time preferences (by using questionnaires), or by studying revealed preferences in actual decisions.

This approach is therefore not aimed at identifying what would be the rationally and ethically correct depreciation rate to be used in studies looking into normative decisions that have impacts over long periods of time, like CO_2 emissions or nuclear waste storage, but rather takes a picture of people perception on the subject.

The DU model, on the other hand, explicitly accounts for time discount only assuming that the overall value of a sequence of outcomes is equal to the discounted sum of the utilities in each period. The distribution of utility across time makes no difference beyond that of discounting. It rules out any kind of preference for patterns of utility over time, e.g. a preference for a flat utility profile over a fluctuating utility profile with the same discounted utility.

This is clearly in conflict with the precautionary approach (see next paragraph), which assumes that the next generations have equal or better opportunities than the current.

The studies show similar biases as 'risk perception' studies. For example:

Gains are discounted more than losses (This is exactly as in risk perception studies: risk of loss is systematically overrated compared to gains)

- Small amounts are discounted more than large amounts;
- In choices over sequences of outcomes, improving sequences are often preferred to declining sequences though positive time preference dictates the opposite
- In choices over sequences, people seem to prefer spreading consumption over time in a way that diminishing marginal utility alone cannot explain.
- The studies seems to demonstrate that respondents ignore the existence of a capital market

The last point indicates that much of the input used to derive a time preference is just a perception bias. When people are asked to choose between $100 today and $110 in a year, this can rationally be answered by considering if the capital market could return more or less than 10%.

3.2 Precautionary approach vs standard economic theory

A classical cost-benefit analysis, in its calculation of the expected present value, will attribute little importance to a possible future disaster with major impacts. This is because the product of quite high costs and a low probability could still be a relatively small number. In addition this number will also have to be discounted. In particular for high discount rates the future thus tends to vanish from the calculations.

This is a reason for scepticism about the treatment of such events by economics, and the development of policy rules that focus more explicitly on uncertainty, and on avoiding at any cost irreversible phenomena and potential disasters.

The precautionary approach is a much referenced environmental policy principle cited in international regulations and policy documents. The most commonly used definition is from the Rio Declaration on Environment and Development from 1992: "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."

By including the last part and referring to only "cost-effective measures to prevent environmental degradation", the definition becomes actually unclear, as cost-effectiveness normally must be evaluated using economic theory. In any case, the most important element in the precautionary principle is that it "shifts the burden of proof" in cases where irreversible or serious damage may occur. In case of foreseen un-acceptable consequences to the environment, an action is to be put in place. Cost-effectiveness is only used to prioritize the different abatement options.

Another difference from standard economic theory is that the environment shall be given the benefit of the doubt in case of uncertainty.

This is quite contrary to the principle in economic theory where the uncertainty, i.e. the lack of knowledge and the inherent possibility of reducing uncertainty by gaining more knowledge, is treated as a (positive) 'option'. This led the committee behind the recommendations formulated in (Norway, 2012) to conclude "When faced with irreversible effects, one should, if the project can be postponed and such postponement enables new information of relevance to decision making to be gathered, take into account the (quasi-) option value associated with a wait-and-see alternative. A positive net present value based on a cost-benefit analysis will not necessarily imply that it is profitable to implement the project immediately. The expected net present value of implementing the project immediately must also exceed the option value associated with the wait-and-see alternative".

It may therefore be noted that uncertainties from the viewpoint of economic theory play prejudicially against a corrective action, while the precautionary approach suggests the opposite.

It may be questioned if some of the assumptions and ideas used in standard economic theory are part of the problem when dealing with global heating and other environmental effects, rather than a solution.

3.3 Integrated Assessment Models

As mentioned, a subject for debate on inter-generational utility functions is represented by long term climate changes. Economists often use Integrated Assessment Models (IAM) to analyse this challenge. Such models combine climatology and economics, and claim to be able to estimate both the costs associated with global emission-abatement measures and the global welfare effects of the greenhouse gas emission levels. In principle, IAM models are used to analyse what is an optimal global level of ambition for climate policy, or to analyse climate policy requirements for reaching a specific target, for example the agreed two-degree target, see (Randalls, 2010). Many of the IAM models are based on standard growth theory, where society invests in capital, education and technology, thus refraining from consumption at present for the purpose of expanding future consumption opportunities.

It is assumed that society will seek to optimise its consumption over time, based on its current and future consumption needs. Professor William Nordhaus (Yale University) has developed what is generally believed to be the best IAM model; the so-called DICE model (Dynamic Integrated model of Climate and Economy: (Nordhaus, 2007). The model expands the traditional growth theory approach. By investing in natural capital today, future reductions in consumption opportunities as the result of climate-induced deterioration are limited. In the DICE model, Nordhaus (2007) studies the trade-off between traditional production investments and climate investments. His findings show that it is profitable to make relatively large investments in traditional activities in an early phase, which also include improved technologies and additional intellectual capital, and only some investments in designated climate measures.

He concludes that this can be achieved by introducing general, harmonised CO_2 taxes at relatively low rates in this early phase. In the longer run, the environmental costs are expected to increase as greenhouse gases accumulate and global warming increases. It will then become profitable to shift investments to much more aggressive, emission reduction measures. This can be achieved through a steep increase in the tax rates in the intermediate and long run. This gradual approach to the climate challenge has been termed the "climate policy ramp"

Many IAM calculations lead to conclusion that actions may be postponed, with a moderate emission reduction effort in the near future. This conclusion depends on debatable choices of assumptions made, including the choice of discount rate.

Whilst Nordhaus (2007) applies a capital-market-based discount rate (5.5%) in his calculations, Stern (2007) uses a much lower discount rate in his calculations (1.4%). This contributes to his arguing in favour of starting early with relatively large, global emission cuts, in sharp contrast to Nordhaus (2007) and many other IAM estimations.

The key point is represented by the comparison between the expenses due to the implementation of greenhouse gas cutting actions (possibly starting in the near future) and the benefits corresponding to avoiding serious damages in a medium term future: a different way of discounting affects the results of such comparison.

Ingham and Ulph (2003) also criticize the fact that the IAM-based computations ignore the possibility that there may exist tipping points in nature, beyond which additional heating may trigger dramatic and irreversible processes (criteria usually referred to in the definition of the precautionary approach).

Since the main consideration is to safeguard against a potential climate-induced disaster with a low probability, it is better to base analysis of the climate issue on a pure risk approach than to base it on a comparison of costs and benefits, as is the approach adopted by most IAM models.

It is also worth noting, (Skjong, 2009), that (IPCC, 2007b) used a totally different approach: the cost effectiveness of a series of measures was calculated and it was found that all measures that cost less than \$50 for preventing a ton of CO_2 equivalent heating effect need to be implemented to reach the 2 degree target. (IPCC, 2007b) therefore defined a limit value for the CATCH of \$50, that was in agreement with a 2˚C target, which many environmental scientist believe is a tipping point.

The "dismal theorem" presented by Weitzman (2009) has generated another debate. The theorem criticises cost-benefit analysis (CBA) of the climate issue, as included in IAM. The basis for the criticism is that we do not know the probability of very serious consequences from global heating. For example, the lack of knowledge relating to rapid global heating and large-scale feedback effects on production and consumption may be non-negligible. Weitzman (2009) also observes that potentially catastrophic feedback effects from increased CO_2 concentrations in the atmosphere are currently omitted from most IAM models. He also criticises the damage functions used in IAM analyses of the climate issue. The standard CBA damage function is quite simplistic. It reduces the welfare equivalent of production in the event of a mean global temperature increase T by a multiplier expressed as (Weitzman, 2011):

$$M(T)=\alpha T^2/(1+\alpha T^2) \tag{12}$$

Rather than the catastrophic scenarios described in other literature, such analyses find a relatively modest effect on world production from large temperature increases. Furthermore, other effects like biodiversity and health effects are ignored in many models.

Nordhaus (2011) accepts the dismal theorem to be important because it may assist in determining when extreme outcomes are of relevance. He argues that the theorem is valid only under special conditions: it assumes strong risk aversion in society, a very fat tail for uncertain variables and, moreover, that society is unable to learn and act in a timely manner. According to Nordhaus, the dismal theorem assumes that the marginal utility of consumption grows infinitely large when consumption approaches zero, as in the case of a disaster. This implies that society will have an unlimited willingness to pay to avert such a scenario, even considering the low probability. If this assumption is true, the expected value of the welfare loss will not be infinite, and the premises underpinning the dismal theorem will be false. That leads us, according to Nordhaus, back to standard cost-benefit analysis, as used by the many IAM models.

The key question asked by Nordhaus is whether the international community does in fact have an infinite willingness to pay for avoiding a very low, but non-negligible, probability that the basis for human existence will be wiped out. He notes, as an example, that the probability of an asteroid hitting the Earth is about 10^{-8} per annum. If the dismal theorem was valid, we would, according to Nordhaus, be willing to pay an unlimited amount for a tiny reduction in this probability. He notes that society does not, generally speaking, behave as if infinite negative utility is associated with catastrophic outcomes at the limit. Besides, Nordhaus maintains that the nature of climate change (unlike asteroid disaster) is such as to give us time to learn, and to postpone the large-scale emission reductions until more effective technologies have been developed. This is obviously contrary to facts: there are programs in place to deflect asteroid impacts, but the technology is far from ready. However, in the next 100 years there might be technology in place, and the probability of the event in the next 100 years is in the order of 10^{-6}. This is contrary to climate change, where much of the technology is ready for use, and the probability of severe consequence in the next 100 years is almost 1, not as severe as a big asteroid impact, but still with severe implications to our welfare.

Pindyck (2011) notes, as did Nordhaus, that Weitzman assumes a utility function exhibiting special characteristics, especially with regard to society's risk aversion. Pindyck believes that marginal utility may be very high when consumption approaches zero, but not that it approaches infinity. If we introduce an upper cap, thus implying that marginal utility approaches a finite level, the willingness to pay will also be finite, according to Pindyck. He agrees with Weitzman that it is reasonable to assume that the probability distributions are fat-tailed (see next chapter). He does not deny the possibility of an extreme climate-generated outcome, and notes that sufficiently fat tails justify swift action without any complex analysis, but he believes that steep emission reductions may also be justified even if assuming thin tails. The last must be correct, see next paragraph.

Weitzman, (2011) argues that the existence of other potential disasters does not eliminate the special cause for concern occasioned by climate change. He could also have chosen different specifications for society's utility function than those adopted in his original analysis. The key point according to Weitzman is that potentially fat tails should make economists less confident about cost-benefit calculations within this area!

3.4 Tails of the probability distributions

Economists often refer to fat & thin tail probability distributions when discussing climate change. The normal distribution, which is much used in economic theory, features a thin tail. A thin-tailed probability distribution implies that the probability decreases exponentially or faster when moving away from the expected value. Hence, there is a very low probability of outcomes that are far from the expected value.

However, many phenomena in economics and elsewhere may have a probability distribution that deviates from this. One example may be stock market fluctuations. On 19 October 1987, the US stock market slumped by 23 percent. Nordhaus (2011) observed that if the stock market had adhered to a normal distribution, we would have observed a 5-percent change in prices only once every 14,000 years. However, historical stock market data show that major fluctuations happen much more frequently than would be indicated by a normal distribution. This is indicative of a probability distribution with fat tails. The reasons are better explained and understood by physicists/mathematicians working in economics by use of Agent Based Models, (OECD, 2011), (Turner, 2011).

Classical economists observe that extreme outcomes will not be very improbable under fat-tail assumptions. The problem with this debate amongst economists when debating climate change, is that the predicted consequences are actually around the expected value of the prediction, so the debate about the tails is rather irrelevant and brings the debate out of focus.

3.5 Role of the discounting rate

As above recalled, the discount rate is a very critical parameter in cost-benefit and cost-effectiveness analysis when costs and benefits are different in their distribution over time, especially when they occur over a long time period. For example in the debate about climate change the horizon may be hundreds or even thousands of years. As an illustration: $1/1.01^{100}$=0.369 and $1/1.05^{100}$=0.0029, a factor difference of 125.A very high discount rate implies that the far future (both costs and benefits) has no impact on a decision now, and will therefore often be in conflict with a precautionary approach. The best illustration of the extreme importance is illustrated by the Stern-Nordhaus debate. It is now well understood that it was a low discount rate that drove the policy conclusions of the Stern report, as opposed to previous cost-benefit analyses of global heating. Stern's cost-benefit analysis of global heating assumed a real discount rate of 1.4% and concluded there was a case for immediate action. Stern used a rather unique argument for setting the depreciation rate for true time preferences exceedingly low. He argued that the only reason for this depreciation was the likelihood that humankind went extinct and was not present to enjoy future consumption. Stern interprets the depreciation factor $e^{-\delta t}$ as the probability that the world exists at that future time, because this is the probability of survival that would apply if the destruction of the world was the first event in a Poisson process with parameter δ. Nordhaus assumed a 5.5% discount rate, and favoured a modest carbon price, increasing over time. The different assumptions of discount rates could explain the whole difference in conclusions. This was verified by Nordhaus, when he ran his DICE model using Stern's discount rates, he got similar results to Stern (Nordhaus, 2007).

There are essentially two ways of deriving discount rates:

- Based on comparing to opportunity costs, and use of the Capital Value theory
- Based on the Ramsey equation

The logic of comparing with opportunity costs is based on the idea that cost-benefit analysis normally uses willingness to pay studies to measure benefits. The opportunity cost is the value that the alternative would have produced. Identifying the costs and benefits of a change involves comparing the result of the proposed change to outcomes without the change (often referred to as the zero option, or the business as usual). Analysts typically observe the value people place on something by observing their willingness to pay, for example by observing market behaviour. So, logically a decision should be made in favour of the change if it is better than without change. This is reflected in the opportunity cost. Obviously, for issues like climate change, the question may be said to relate to the observable market behaviour or the stated willingness to pay.

In finance, the capital value theory is used to determine a theoretically appropriate required rate of return of an asset, if that asset is to be added to an already well-diversified portfolio, given that asset's non-diversifiable risk. The model takes into account the asset's sensitivity to non-diversifiable risk (also known as systematic risk or market risk), often represented by the quantity beta (β) in the financial industry, as well as the expected return of the market and the expected return of a theoretical risk-free asset. The market reward-to-risk ratio is effectively the market risk premium

$$E(R_i) = R_f + \beta_i\,(E(R_m) - R_f) \tag{13}$$

where $E(R_i)$ is the expected return on the assets, $E(R_m)$ is the expected return in the market, R_f is the risk free return and $\beta_i = Cov\,(R_i, R_m)/Var\,(R_m)$

The Social Time Preference Rate, derived by the Ramsey approach, represented by r, is the sum of these two components, i.e.

$$r = \rho + \mu\, g \tag{14}$$

The Social Time Preference Rate has two components:

- The rate at which individuals discount future consumption over present consumption, on the assumption that no change in pro capite consumption is expected, represented by ρ
- An additional element, if pro capite consumption is expected to grow over time, reflecting the fact that these circumstances imply future consumption will be plentiful relative to the current position and thus have lower marginal utility. This effect is represented by the product of the annual growth in pro capite consumption (g) and the elasticity of marginal utility of consumption (μ) with respect to utility, which is defined as the percentage fall in the marginal utility when consumption increases by one per cent.

Each element of Social Time Preference Rate is examined in turn below.

Estimates of ρ: This comprises two elements:

- Catastrophe risk premium (λ); and
- Pure time preference (δ).

The first component, catastrophe risk, is the likelihood that there will be some event so devastating that all returns from policies, programmes or projects are eliminated, or at least radically and unpredictably altered. Examples are natural disasters, major wars etc. Newbery (1992) estimates λ as 1.0, Kula (1987) as 1.2, Pearce and Ulph (1995) as 1.2, OXERA (2002) as 1.1 currently and 1 in the near future. It should be noted that in risk analysis, the risk component is explicitly quantified. A risk premium should therefore not be included in the discounting, as this would account for the same effect twice. Alternatively a risk premium may be calculated from the risk model (Skjong and Lereim, 1988).

The second component, pure time preference, reflects individuals' preference for consumption now, rather than later, assuming an unchanging level of consumption pro capite over time. In (Scott, 1977) and (Scott, 1989) δ is estimated as 0.5. Other literature suggests it lies between 0.0 and 0.5. However, if zero, this implies pure time preference does not exist, which is not regarded as plausible by most economists.

The UK Green Book (UK, 2011) concludes that the evidence suggests that these two components indicate a value for ρ of around 1.5 per cent a year for the near future. Scott (1977) derives a central estimate value of 1.5 from past long-term returns on savings. A later estimate in (Scott, 1989) updated this estimate to 1.3. However, this was based on United States, as well as UK, evidence. OXERA (2002) estimates ρ to lie between 1.0 and 1.6.

Estimates of μ: According to (UK, 2011) the available evidence suggests the elasticity of the marginal utility of consumption (μ) is around 1. Pearce and Ulph (2005) estimate a range from 0.7 to 1.5 with 1.0 being considered defensible. Cowell and Gardiner (1999) Cowell and Gardiner (1999) estimate μ as being just below or just above 1.0; OXERA (2002) estimate a range from 0.8 to 1.1.This implies that a marginal increment in consumption to a generation that has twice the consumption of the current generation will reduce the utility by half.

Table 10. Discount Rates Derived by Ramsey Formula.

Reference	*P*	*μ*	*g*	*r*
Stern (2007)	0.1	1	1.3	1.4
Quiggin(2006)	0	1	1.5	1.5
Cline (1993)	0	1.5	1	1.5
Garnaut (2008)	0	1-2	1.3	1.3-2.6
Harrison (2010)	0-3	0.2-4	1.2-2.1	0.24-11.4
Nordhaus (2007)	1.5	2	2	5.5
Weitzman (2007)	2	2	2	6
Arrow (2007)	0	2-3	1-2	2-6
Dasgupta (2006)	0	2-4	1-2	2-8
Gollier (2006)	0	2-4	1.3	2.6-5.2
UK (2011)	1.5	1	2	3.5

Harrison (2010) also gives an overview of discount rates used by governments and governmental agencies. This is reproduced in Table 11, with some updates since 2010.

Table 11. Discount rates in national guidelines.

Country	*Agency*	*Rate*
Philippines		15%
India		12%
Pakistan		12%
Developing Banks	World Bank	10-12%
	Asia Development Bank	10-12%
	Inter-American Development Bank	10%
	European Bank for Reconstruction and Development	10%
	African Development Bank	10%
New Zeeland	Treasury and Ministry of finance	8% (10% 82-2008)
Canada	Treasury Board	8% (10%, 76-2007)
China		8%
South Africa		8%
USA	Office of Management and Budget	7% (10%, < 1992)
USA	EPA	2-3% (Test 7%)
European Union	European Commission	5% (6%, 2001-2006)
Italy	Central Guidance to Regional Authorities	5%
The Netherlands	Ministry of Finance	4% (risk free)
France	Commissariat General du Plan	4% (8%, 85-2005)
UK (*)	HM Treasury	3.5% (see Table)
Norway(*)	Norway (2012)	4% (See Table)
Germany	Federal Finance ministry	3% (4%, 99-2004)

(*) Updated as compared to Harrison (2010)

Estimates of g: Maddison (2001) shows growth pro capite in UK to be 2.1 per cent over the period 1950 to 1998. Surveying the evidence, the UK (2013) "Treasury paper Trend Growth: Recent Developments and Prospects" also suggest a figure of 2.1 per cent for output growth to be reasonable. This estimate removes the impact of net migration. In UK (2011) the annual rate of g is therefore put at 2 per cent per year.

The calculated Social Time Preference Rate by UK (2011) is therefore:1.5% + 1 × 2% = 3.5%.

These and other results from use of Ramsey's formula may be found in Table 10.

Where the appraisal of a proposal depends materially upon the discounting of effects in the very long term the UK (2011) view is that a lower discount rate for the longer term (beyond 30 years) should be used. The main rationale for declining long-term discount rates results from uncertainty about the future. This uncertainty can be shown to cause declining discount rates over time, Weitzman (2001) and Gollier (2002). In light of this evidence, UK (2011) recommends that for costs and benefits accruing more than 30 years into the future, appraisers use the schedule of discount rates provided in Table 12.

Table 12. Long Term Discount Rates (UK).

Years	*0-30*	*31-75*	*76-125*	*126-200*	*201-300*	*301-∞*
Discount rate	3.5%	3.0%	2.5%	2.0%	1,5%	1%

The recommendation in Norway (2012) is slightly simpler, but also suggests a declining rate, see Table 13.

Table 13. Long Term Discount Rates (Norway).

Years	*0-40*	*40-75*	*75-∞*
Risk free Rate	2.5	2	2
Risk Premium	1.5	1	0
Risk Adjusted Rate	4	3	2

From 1967 to 1999, Norway used an approach where the discount rate was based on the Ramsey model. Based on a report in 1967, in which it was assumed that $\rho = 1$ percent, $\mu = 3$ and $g = 3$ percent, the discount rate was put at 10 percent in a government circular from 1975. In a circular from 1978 the discount rate was changed to 7 percent. When revising the cost-benefit analysis framework in 1998, the assumption of a small, open economy was held to be reasonable for Norway. Therefore, the risk-free interest rate and risk premiums were deemed to be increasingly determined by international markets. Hence, estimates of the relevant discount rate were based on the Capital Asset Pricing Model. The Ministry of Finance guides from 2000 and 2005 discuss, in more detail, how the model may be adapted to provide an expression for a reasonable discount rate for use in cost-benefit analysis. A circular in 1999 stipulates a risk-free real rate of 3.5% should be assumed in cost-benefit analysis.

3.6 Conclusion (depreciation rates)

It is observed that there are many diverging views on depreciation rates to be used in cost-benefit and cost effectiveness studies. The assumptions have very large consequences on policy decisions where the effect of the decision has long term effects, like the greenhouse gas emission, and CO_2 emissions in particular, where emission now have effects over periods of thousands of years.

However, it is observed that there is some tendency that the depreciation rates are now typically recommended at around 3% in developed economies. In some of the fast growing economies the discount rates are much higher, which can be easily justified by the Capital Value Model. The challenge with global polices for greenhouse gas emission reduction can be understood in this context, because at these high rates, few abatement technologies are cost effective, and policy recommendations from the models will tend to be wait-and-see rather than a precautionary approach.

It should also be observed that the approach used in IPCC(2007) is less dependent on these assumption, as it makes a direct link between the politically agreed 2˚C target and the cost effectiveness of available abatement technologies.

4. EXAMPLES RELATED TO SUSTAINABILITY ORIENTED DESIGN

As described in Chapter 1, general aspects such as economic, human and environmental terms should be considered for sustainabe design. In this chapter, recent works related to risk-based design are firstly reviewed, which are mainly related with the human aspects (fatality) and are applied to regulatory process. Later, lifecycle design examples including evaluation of environmental aspect and adaptation to climate change are considered.

4.1 Probability based design

In this section, recent applications of probability based design are reviewed: these applications, however, do not cover the whole spectrum of consequences included in the concept of sustainability, but concentrate on single aspects.

Vassalos (2012) reported the recent history of the Design for Safety (Risk-Based Design) concept and presented implementation examples, highlighting challenges opportunities of the concept. An applications to contemporary regulatory development, the IMO Passenger Ship Safety, is reported. Modern safety expectations are expressed as a set of specific safety goals and objectives, addressing design (prevention), operation (mitigation) and decision making in emergency situations with an overarching safety goal, corresponding to *no loss of human life* due to ship related accidents.

The concept of alternative and/or equivalent design, more recently summarised in (IMO, 2013a), is exemplified with an application to fire safety regulation, in which designs not strictly complying with the existing prescriptive fire safety regulations can be accepted, provided that such designs can be shown to be at least as safe as the design made in accordance with the conventional rules by using the risk-based approach. In the risk analysis, example of evacuation simulations by which the number of fatalities in the fire scenarios is computed, and the dynamic flooding/survivability simulation is used to evaluate the consequence of the flooding scenarios.

In (Vassalos, 2012), the concept of the Safety Management System (SMS) is discussed, too. SMS is a lifecycle process, starting at the concept design stage and continuing throughout the life of the vessel. In this process, safety must be continuously monitored and reviewed to ensure developments/changes in the design, and its operations are reflected in the way safety is managed. As an example of life-cycle safety management system, the development of iStand is described, a Decision Support System (DSS) installed on-board with general features such as: real time sensors and hardware integration, vulnerability log, critical assessment, corrective action search etc.

In the short report by Andrews et al. (2012), the risk-based design approach is seen as a classical application of the holistic/multi-objective ship design concept, where in addition to safety issues represented by a variety of hazards, economic and environmental impact aspects are jointly optimized for best design solutions.

Boulougouris and Papanikolaou (2013) reported the application of risk-based design to combat ships. They used risk-based assessment methods to the evaluation of the survivability of surface combatants after damage. In this case, damage stability criteria are coupled to a probabilistic model of the damage due to weapon impact. For the estimation of the probability of survival after damage in waves, two methods are applied: the quasi-static approach, in which semi-empirical deterministic criteria are used and a full dynamic flooding/capsizing approach in which a time domain flooding and/or capsizing simulation code is used. Also, the use of the flooding simulation by the pressure-correction method implemented in a commercial code is reported. The introduced method is applied to the assessment of the damaged stability of a generic frigate operating in specified seaway conditions, and typical results of this type of study are presented.

Given the ever increased amount of historical records with improved accessibility, a situation of "flood with data, but difficult to harvest" is becoming a common situation, when trying to derive statistics from accident/incident data. Cai and Konovessis (2012) elaborates on a method for integrating the effort devoted to marine accident investigation into a risk-based design framework. In this concept, basic ship design parameters and operational parameters which affect the safety performances are firstly investigated. Then the historical accidental events are transformed into the accident database by using these parameters. Next, a risk model is built, using a Bayesian Belief Network (BBN) based on the database. The parameters in the risk model are defined by using learning techniques such as Bayesian Structure Learning or Bayesian Parameters Learning. The model is then used to identify a risk-based optimal design solution. The concept is demonstrated through an investigation on fire safety onboard passenger ships. Even though the demonstration shown in this paper is very simple, the proposed concept is very interesting in that they proposed the development of accident database system, subsequent model training, and application in risk analysis, for the implementation of risk-based ship design.

Even though a risk-based approach has been applied a few times in the rule-making process or for novel ship designs, there are difficulties and challenges in applying RBD concepts to conventional ship designs. Lee et al. (2012) discuss how to meet these challenges. In their paper, the existing concepts and methodologies for risk-based design of ships and marine systems are reviewed. Next, difficulties in applying these concepts in a practical design environment are discussed, together with possible ways of overcoming such difficulties. The potentiality of the approach are shown in an application to the pilot design of a new concept container vessel and of CO_2 carriers. In their conclusions the authors note that the "standardization of Risk-based ship design" is necessary to establish the RBD concept in practical ship design.

Recently, applications of risk-based design methods have been proposed and developed in various EU funded research projects. NMRI (National Maritime Research Institute) in Japan also carried out a research on development of fatality risk evaluation method as a cooperative research with the Japan Shipbuilding Research Association, and now continue to carry out researches on more advanced risk-based design methods. Kaneko et al. (2012) reported about present status and future plan of the research project related to further enhancement of risk-based design in NMRI covering the items below.

Accident scenarios and estimation of their frequencies

In this part of the research, improvement of HAZID method, which is the first step of risk assessment for identification of possible hazards relevant to the considered ship, is discussed for more suitable development of accident scenarios. In particular, typical form of the HAZID sheet and the HAZID database as well as the use of historical accident data is discussed, by which efficient hazard identification and development of accident scenarios might be possible. Moreover, the use of the field measurement data such as AIS data for estimation of frequency of initiating events (collision situation) is reported with some examples of ship trajectories.

Consequence analysis method

This part of the investigation focuses on flooding and fire as main causes of serious accidents with fatalities and, accordingly, on simulation programs of fire escalation, flooding (in the time domain) and evacuation for consequences analysis in risk evaluation. In the paper, use of software for fire propagation and evacuation simulations is reviewed and discussed with some results. Plans for the development of CFD simulations of HNS (Hazardous and Noxious Substances) and oil spillage out through breaches in a tanker hull are also reported.

Data conversion programs

The paper also discusses about the necessity of data conversion programs, for example from internal data of design tools into input format for programs carrying out consequence analysis.

Validation of the approval procedures

When a ship is designed by prescriptive methods (rule-based design), authorities such as Classification Societies can easily approve the design based on the existing rules. On the other hand, in the approval process of a ship by risk-based design, accident scenarios, frequencies, probabilities and consequences should be validated by the designer and by the approval body. In addition, a verification of the simulation and computation programs used in risk evaluation should be carried out. In the paper it was commented that approval authorities carry out this activity directly and that open source programs are desirable for the verification of simulations. Another practical example of risk-based design, is reported in (Choung et al., 2012) where they carried out a specific risk-based design using Structural Reliability Analysis (SRA). The structural safety assessment of a longitudinal stiffener of the outer shell of a double hull tanker is carried out. A first yielding limit state function in bending is defined for the local supporting member subjected to lateral pressure and hull girder longitudinal stress. A probabilistic model of design variables is set, based on the literature review. Then, the probability of failure is computed using a commercial reliability program for both full-load and normal ballast conditions, at different heading angles. Based on the results of SRA, a Design Safety Level (DSL) is evaluated as a combination of the computed probabilities and compared to a Target Safety Level (TSL) defined according to (Denmark et al., 2004a), assuming "no serious" failure consequences and a "ductile failure with no reserve capacity" as "failure development" category. Finally, the assessment results for design modification cases (different stiffener dimension) are reported to show the validity of the proposed procedure.

It is here noted that a more updated source for the definition of target probabilities of failure is provided in (IACS, 2006b)

4.2 Lifecycle Design

For a sustainable design of ship and marine structures, it is important to evaluate also the environmental impact in the lifecycle of the structures themselves. (Aspen et al., 2012) reported current status, opportunities and barriers for integrating the lifecycle analysis in ship design processes. Life cycle assessment (LCA) and life cycle costing (LCC) concepts are reviewed in this paper. The authors account for the adverse environmental effects from the entire lifecycle of products and processes considering raw material extraction, processing, product manufacture, transportation, operation, maintenance, repair and scrapping. In the paper, the application of the concept to vessel designs is discussed, and different LCA software programs which can be used for the purpose are reviewed. Next, in order to demonstrate the applicability of the concept, a case study of two longline fishing vessels is reported: a conventional vessel is compared to a newer version where innovative solutions (e.g. the moonpool technology) are employed. Results were related to the functional unit of 1 kg of fish captured and brought to shore for further processing. The analysis uses four environmental indicators from the CML (Institute of Environmental Sciences at Leiden University) Baseline characterization method:

- Acidification potential (AP) (Unit: Kg SO_2 Eq)
- Global warming potential (GWP 100a) (Unit: Kg CO_2 Eq)
- Photochemical oxidation potential (POCP) (Unit: Kg Ethylene Eq)
- Stratospheric ozone depletion potential (ODP) (Unit: Kg CFC-11 Eq)

In addition, weights are added in the various inventory flows based on the willingness to pay to avoid the various impacts from the lifecycle of the product, so that it becomes possible to produce a unique indicator that shows environmental impacts as damage costs. As a result, a difference in eco-efficiency shows the advantage of the new vessel. The paper further discusses the relationship between the framework of environmental regulation and the LCA (environmental impact indicators). Difficulties in introducing the LCA and LCC into marine systems design are discussed, related to the definition of the functional unit, system boundaries and data collection.

Environmental performance is now becoming an important subject in the maritime industries. However, ship designers may not be able to find the appropriate tools to evaluate the environmental performances during the lifecycle of the ships and marine structures. Even though tools are found, an holistic approach is still missing. Fet et al. (2012) and Fet et al. (2013) report about existing environmental assessment tools and introduce systems engineering as an approach to holistic life cycle design. Figure 5 shows the environmental performance improvement tools classified by the scope of temporal concern and of environmental concern.

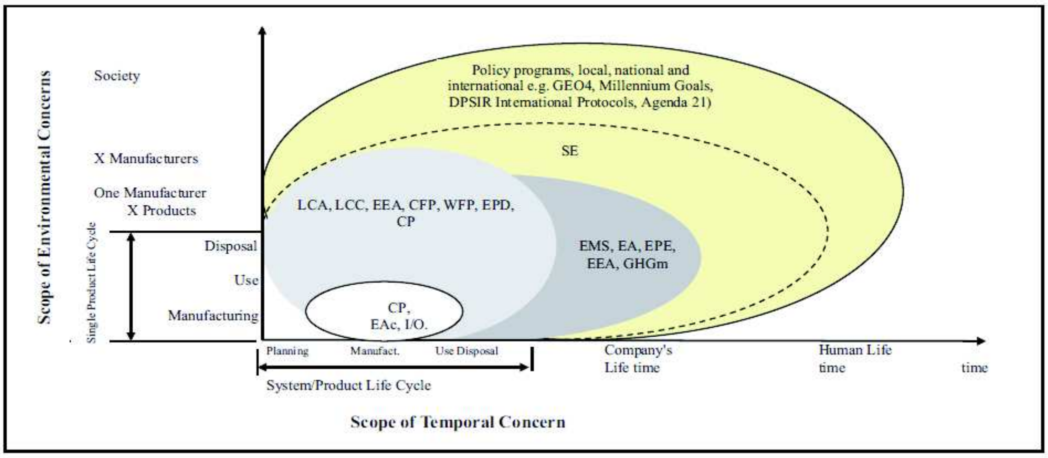

Figure 5. A Classification of methods and tools for environmental performance improvement [Fet et al, 2012].

The inner smallest area is related to production processes, for which CP (Cleaner Production, in the narrow sense), EAc (Environmental Accounting) and I/O (Input-Output Analysis) are appropriate tools. The next area is related to products and their life cycles: here appropriate tools are LCA (Life Cycle Assessment), LCC (Life Cycle Costing), EEA (Eco-Efficiency Assessment), CFP (Carbon Footprint of Products), WFP (Water Footprint of Products), EPD (Environmental Product Declaration) and CP. Area 3 represents the company lifetime: EMS (Environmental Management System), EA (Environmental Auditing), EPE (Environmental Performance Evaluation), EEA, GHG management are relevant. To achieve a sustainable development in a long-term perspective, policy programs and international regulations are necessary, which are illustrated with the outermost circle in the figure. The paper also describes the advantage to introduce System Engineering (SE) and shows how environment impact assessment tools can be used in the SE process. The authors conclude that the SE has proved to be a systematic tool for a methodology for Life Cycle Management (LCM), and can be used as the framework for design for environment.

In conventional ship design, the ship structure is usually designed to minimize the overall weight of the vessel, meeting constraints such as strength requirement introduced by regulations and standards. This approach, however, does not take into account the maintenance and repair costs incurred by the shipowner in the lifecycle of the vessel. (Temple and Collete, 2013) assessed year-by-year costs of a naval vessel over her service life to determine a lifecycle maintenance cost value for the ship. They use a lifetime structural model that captures the effect of degradation due to corrosion and fatigue. For fatigue model, a probabilistic formulation based on a classical S-N approach is used, by which the probability that the fatigue crack is found is estimated and the corresponding fatigue costs can be calculated considering the repair cost. For corrosion damage, a time-dependent wastage model is used to estimate the thickness reduction in each year of the vessel's service life. Corrosion costs due to plates replacement because of local corrosion and due to degradation in the overall global strength are considered. The model includes also scheduled maintenance, unplanned-maintenance and costs associated with dry-docking to carry out repairs. An optimization using MOGA (Multi-Objective Genetic Algorithm) is adopted to minimize both the structural volume and the lifetime maintenance cost for the mid-ship section of a nominal DTMB-51 hull form. The scantlings of the panels in different functional locations are used as design variables of the optimization. By comparing the optimum solutions on a typical Pareto frontier, the trade-offs between structural weight and lifecycle maintenance cost are investigated. For example, as the design become lighter, the fatigue costs increase from near zero to a significant part of the lifetime maintenance costs for the vessel. The conclusion is that, by incorporating the lifetime maintenance costs into the initial evaluation of the structural design, it is possible to optimise the performance over the whole operational life of the vessel.

Based on the concept of holistic risk evaluation, already outlined in preceding issues of the report of committee IV.1 (Design Principle and Criteria) of ISSC (Brunner et al., 2012) (Moore et al., 2009), a lifecycle structural optimization of the mid-ship section of a double hull tanker was carried out in (Kawamura et al., 2013). They defined the optimization problem as a maximization of the life-cycle benefit (*LCB*) as shown below.

$$LCB = R_{OPE} - LCC \tag{15}$$

where R_{OPE} is the lifecycle revenue and *LCC* the lifecycle cost, evaluated as:

$$LCC = \sum_{i=1}^{t_{life}} (C_{OPEi} + C_{INSi}) + C_M + C_{RISK} + C_I \tag{16}$$

where C_{OPEi} is the annual operational cost for *i*-th ship-year, C_{INSi} is the insurance cost per year, C_M is the maintenance cost, and C_I is the construction cost. It is noted that the lifecycle risk of the ship (C_{RISK}) is evaluated as a part of the objective function (*LCB*) in this optimization. Within the lifecycle risk, the components due to CO_2 emissions, to the oil-outflow risk and to the risk of structural failure are considered. CO_2 emissions are evaluated by life cycle assessment (LCA), while possible oil-outflow consequences are computed according to the MARPOL convention. The risk of failure is evaluated by structural reliability analysis (SRA) of the longitudinal strength of the ship, adopted to compute the probability of failure. Based on these risk models, various single objective optimization problems are solved by genetic algorithm, maximising the *LCB* considering (a) only the risk of oil outflow, (b) only the impact of CO_2 emissions, (c) only the risk of failure. Finally *LCB* has been maximised considering all the contributions (holistic risk). The optimal solutions of these separate problems are compared to discuss the influence of each objective function and to show the meaning of including an holistic perspective in the design.

4.3 Lifecycle Design Considering Future Climate Change

Despite the efforts part of the world is making to limit this effect, according to the Intergovernmental Panel of Climate Change (IPCC), the globe is definitely experiencing a climate change. One of the implications is that frequencies and intensities of extreme weather events are likely to increase. For an effective lifecycle design of ships and marine structures, it is crucial to estimate future trends in the met-ocean conditions. A possible increase in significant wave height (SWH), f.i., would in fact increase wave-induced structural loads to a higher level than in the present situation.

Bitner-Gregersen et al., (2013) published a very valuable monograph about climate change, in particular wave climate and its impact on ship and offshore structural design. They reviewed IPCC reports and recent papers related to climate change, and summarize the prediction of future changes in storminess, wind and waves. Their conclusions about the trends of wave climate are as follows.

There is a consensus about an increase in significant wave height from the middle of the 20th century to the early 21st century in the northern hemisphere winter, at high latitudes in the North Atlantic and the North Pacific, while there has been a decrease at souther latitudes of the northern hemisphere. The increase of the 99-percentile significant wave height (SWH) has been observed to be up to 0.5% per year. However, if records are extended back to late 19th century, the picture changes, as studies show that storminess and wave heights in the late 19th/early 20th centuries were about the same as near the end of the 20th century. Thus, it is unclear if the increase observed during the last 4–5 decades is caused by anthropogenic climate changes or is just a manifestation of long-term natural variability. Regional increases in wind speeds and wave heights are observed, too, more pronounced in extreme values than in the average ones. The increase in the 20-years return period SWH is generally in the range of 0.5-1.0 m in the North and Norwegian Seas, immediately west of the British Isles, off the northwest of Africa, around 30°N from the east coast of the United States to 50°W and in the Pacific between 25°N and 40°N and from the west coast of the United States to 170°W. Increases up to 18% for the 99th percentile SWH have been reported for the southern North Sea. There are indications that the increase in extreme wave heights may reach more than 10% above present day extremes in some areas. Projections are however influenced by: choice of climate model, emission scenario and downscaling method for waves. The uncertainties affecting the estimated increase is of the same order of the estimates itself, so they should not be ignored when impacts of climate change on design and operation of ship and offshore structures are considered.

The authors propose to deal with climate changes as shown in Figure 6, in which changes in met-ocean conditions and relevant uncertainties are integrated as a part of the risk based design.

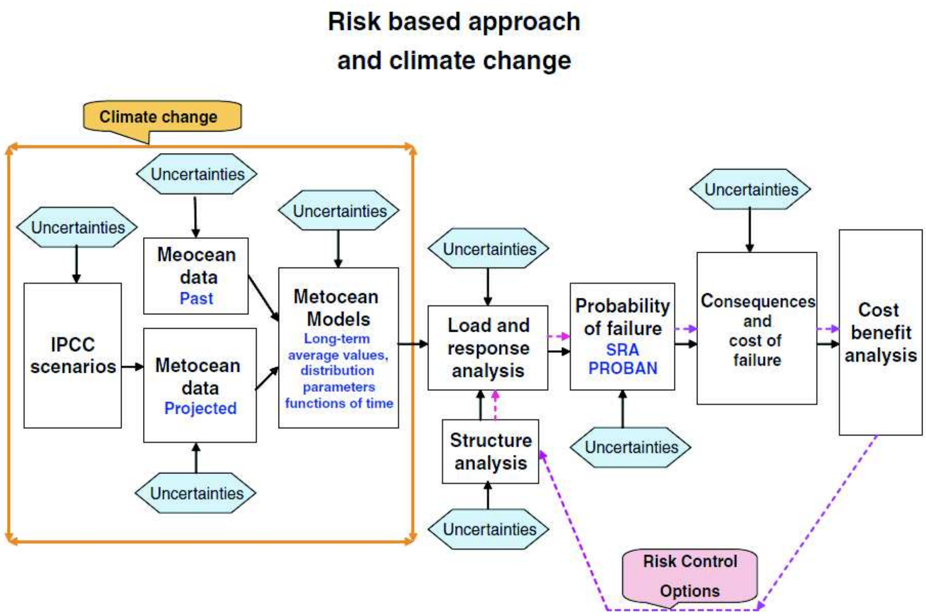

Figure 6. Position of climate changes in a Risk-based approach (Bitner-Gregersen et al., 2013).

Finally, based on the analysis of wave climate change, they investigated the potential impacts of climate change on a tanker design by using structural reliability analysis (SRA). A limit state function for hull girder collapse is formulated as follows:

$$g(\mathbf{X}) = M_U \cdot X_R - (M_{WV} \cdot X_{st} \cdot X_{nl} + M_{SW} \cdot X_{sw}) \tag{17}$$

where M_{SW} is the random still water bending moment, M_{WV} is the random wave bending moment, M_u is the random ultimate capacity while X_R, X_{st}, & X_{nl} and X_{sw} represent model uncertainty factors for the capacity, wave-induced bending moment and still water bending moment, respectively. Randomness of M_{WV} is evaluated by analysing structural response (RAO) using hydrodynamic analysis. Short- and long-term response analyses were carried out to get annual extreme value distribution. When evaluating short-term response, the increase of the extreme SWH (0.5, 1.0 and 2.0 m) corresponding to wave climate change is considered in this study. The results of SRA are compared with those of the base case without increase of SWH. It is concluded that observed and projected changes in climate will have large effects on tanker design practice. The presented results show that, in order to maintain the safety level, the steel weight of the deck for net scantlings should be increased by 5–8% if the extreme SWH increases by 1 m.

The authors also conclude that, in case of climate changes leading to more extreme weather, rules for tankers would need revisions in order to maintain the same structural reliability level. This could be done either by revising the IACS formula for the characteristic wave bending moment or by increasing the partial safety factor for the wave bending moment. Alternatively, one could consider adopting direct calculation of the characteristic wave bending moment and applying the environmental model inclusive of climate changes in the calculation.

Vanem and Bitner-Gregersen (2012) presented a Bayesian hierarchical space-time stochastic model in order to predict future trends of the significant wave height. They used the database of the ERA-40 project, including data of significant wave height sampled every 6^{th} hour from 1958 to 2002 in the North Atlantic Ocean. By such data, the stochastic time-dependent model of the significant wave heights is developed, including long-term temporal trend, seasonal components, conditionally dependent term of the nearest neighbour locations, etc. Bayesian inference and MCMC (Markov Chain Monte Carlo) techniques are used to identify the parameters in the model. It is noted that not only the original data, but also the log-transformed data are applied to construct the stochastic model. From the model, an increasing trend in the significant wave height is observed in the recent 50 years. It is possible to extrapolate these oservations into the future to predict future trends, even though the predicted results might be uncertain. It is reported that an increase in the monthly maximum significant wave height of about 1.6m in 100 years is predicted by using the proposed model with the original data. An increase of 10-15% in 100 years is expected by using the log-transformed data.

Further, the relation between such results and the calculation of future environmental loads and responses is discussed in the paper. The long-term trends obtained by the prediction are incorporated into the joint distribution of significant wave height and wave period based on the $ERA_{interim}$ data. Concretely, it is assumed that the joint distribution ($f_{H_S,T}(h,t)$) can be constructed by the product of a 3-parameter Weibul distribution of significant wave height ($f_{H_S}(h)$) and a log-normal conditional distribution of wave period $f_{T|H_S}(t)$ as shown in Eq. 18 below

$$f_{H_S,T}(h,t) = f_{H_S}(h) f_{T|H_S}(t) \tag{18}$$

To predict the shape of the joint distribution function in the future, the location parameter and the scale parameter of the 3-parameter Weibul distribution are modified using the predicted trend contribution of significant wave height (in this paper $\mu_{ct} = 1.6m$ and $\sigma_{ct} = 0.39m$ is used as an example), while the log-normal distribution is not assumed to change due to the climatic trends.

Figure 7 shows the environmental contour lines of H_S and T_Z for the North Atlantic location with original and modified data. As expected, the modification of the distribution of significant wave height moves the contours to the right. Further, it is observed that the contours are narrowed and the maximum 1-, 10- and 25- return H_S and related T_Z are increased.

Finally, the 25-years stress amplitude and response period for a considered oil tanker have been calculated in the paper incorporating the effect of the climatic trend. A significant increase in the 25-year stress amplitude (7%) is shown, with an increase in the zero-crossing period of 2%. The authors conclude that even though the presented results are used for illustration purposes only and any evaluation would be unavoidably affected by uncertainties, the effect of climatic changes in the wave climate are not negligible and might have impact on load and response calculation of floating structures.

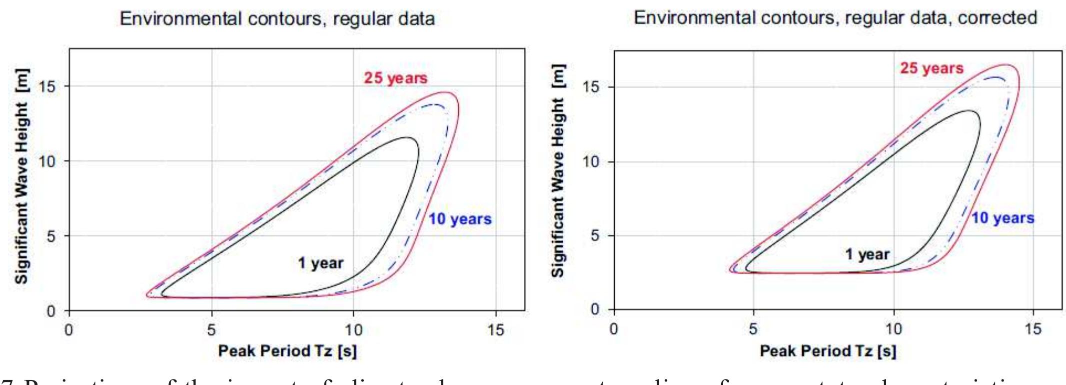

Figure 7 Projections of the impact of climate changes on contour lines for sea state characteristics prediction (Vanem and Bitner-Gregersen, 2012)

5. REGULATORY FRAMEWORK FOR MARINE STRUCTURES

Some of the recent implementations of the regulatory framework at IMO will be recalled in the following. The latest developments of goal based standards will be covered first, while later a short review of the ongoing evolution of requirements targeting particular environmental aspects will be presented. Finally, a few notes regarding the normative framework of other ship activities will be reported.

The latest IMO strategic plan for the period 2014 to 2019 reiterates that the mission of the IMO is to enhance not only the safety and security of shipping but also the sustainability and environmental impact of shipping: “The mission of the International Maritime Organization (IMO), as a United Nations specialised agency, is to promote safe, secure, environmentally sound, efficient, and sustainable shipping through cooperation. This will be accomplished by adopting the highest practicable standards of maritime safety and security, efficiency of navigation and prevention and control of pollution from ships, as well as through consideration of the related legal matters and effective implementation of the IMO’s instruments, with a view to their universal and uniform application” (IMO, 2014d)

It is clear that the IMO intends to continue along the path set over previous periods identifying those effects from shipping that adversely affect the environment whilst ensuring that shipping is able to develop further sustainable practices.

5.1 Development of Goal Based Standards at IMO

IMO, 2011e listed, in the High Level Action Plan and Priorities for the 2012-2013 biennium, the High Level Action (HLA) 10.0.1 “Further develop measures to apply goal-based standards for maritime safety and environmental protection” including the two planned outputs:

10.0.1.1 Implementation of goal-based new ship construction standards for tankers and bulk carriers

10.0.1.2 Development of goal-based ship construction standards for all types of ships, including safety, security and protection of the marine environment

This re-proposed the situation already analysed in the previous term of this committee, characterised by two types of initiatives at IMO in the field of Ship Construction Standards, both related to the term Goal Based Standards (GBS) and in line with the concept it represents. GBS is in fact a term that relates to how IMO wants to structure and justify the maritime regulatory system in general. The reference is to a framework that reports with a ‘top-down approach’ overall goals, objectives, general and specific requirements organised in a hierarchical, coherent and transparent way.

While the GB way of organising the framework is specifically devoted to enforce the qualities of transparency and coherence, it does not imply a specific choice on how the various objectives (particularly those at upper levels) are set and, consequently, how the coeherence between the various levels should be enforced (and checked).

IMO, 2011d is the most updated IMO document containing GBS Guidelines. In the title such Guidelines are defined as ‘generic’. Quoting from paragraph 2: ‘It should be noted that these Guidelines are generic and where they use phrases such as “required level of safety”, this does not imply any preference for a specific technical approach’.

This explain why two different targets have been sought in the last years at IMO under the same term of GBS:

- the development of Construction Standards for Bulkers and Tankers (GBS/B&T), first separately for the two class of ships and, more recently, for the two classes together. In this case, the formulation of goals and their verification are carried out with a deterministic approach
- the development of a procedure for the formulation of Construction Standards for ships based on risk evaluation (GBS/SLA: safety level approach). In this case, the formulation of goals and and their verification is carried out with probabilistic methods

In the following part of the chapter, the recent developments of IMO activity in these two directions will be briefly summarised

5.1.1 IACS Harmonized Common Structural Rules for Bulk Carriers and Tankers

The IACS Harmonized Common Structural Rules for bulk carriers and oil tankers (CSR-H) (IACS, 2014a) are a declination of the goal based standards at the level of tier IV. The Harmonised Structural Rules are now in the audit process at IMO: accordingly, satisfaction of the goals and especially of functional requirements is being verified.

The IACS CSR-H rules (IACS, 2014a) were adopted on December 18th, 2013. They will enter into force on 1st July 2015 replacing the IACS Common Structural Rules for double hull oil tankers, (IACS, 2012b) and the IACS Common Structural Rules for bulk carriers, (IACS, 2012a).

The IACS CSR-H Rules are divided in 2 parts. Part one contains common requirements to both vessel types (oil tankers and bulk carries). Part two contains all requirements that are ship type specific.

In order to understand the approach used in the CSR-H rules, IACS published the technical background information (IACS, 2014b). The document is based on the same main structure as the CSR-H rules.

A consequence assessment (CA) has been carried out by IACS members to assess the impact of the new CSR-H rules on the design of vessels. (IACS, 2014c) summarises the analyses and results of the CA. The CA was carried out on the following oil tanker types: VLCC, Suezmax, Aframax, Panamax, Handymax and different bulk carrier types: Capesize, Babycape, Panamax, Handymax. The design of the sample vessels has not been altered. Same materials and structure element arrangement were used. The CA analysis was carried out for the two ship types (bulkers and tankers) respectively against the common structural rules for bulk carriers (CSR-BC) and the common structural rules for oil tankers (CSR-OT).

The analyses covered the local scantling requirements (yielding, buckling and simplified fatigue assessment), hull girder ultimate residual strength and direct strength assessment (yielding, buckling and fatigue assessment). The general result of the CA is that, for both ship types in all sizes of vessels, in most areas of the hull structure the scantlings according to CSR-OT and CSR-BC do not satisfy the requirements of the new CSR-H rules. Vessels dimensioned according to the CSR-H will have increased scantlings and weight.

The CSR-H rules were developed in the main frame of the goals based standards (GBS). To demonstrate that top-level goals and objectives have been met, the Rules were developed using a hierarchical framework as shown in Figure 8. The framework of the Rules represents a 'top-down approach' that provides transparency and ensures that structural requirements developed reflect the overall objectives (IACS, 2014d).

The issues of the Rule framework are addressed as follows:

The Objectives state the clear and unambiguous goals of the Rules with respect to safety and performance aspects. These objectives provide the basis for deriving the detailed structural acceptance criteria.

The Systematic Review identifies and evaluates the hazards due to operational and environmental influences and the likely consequences of these on the structure of a ship, in order that these can be addressed in the Rules and thereby minimised. The consequences include those that have an effect on the safety of life, the environment and property (ship and cargo). The Systematic Review also identifies whether some of the risks or hazards to the structure are controlled by other standards or regulations (e.g. MARPOL).

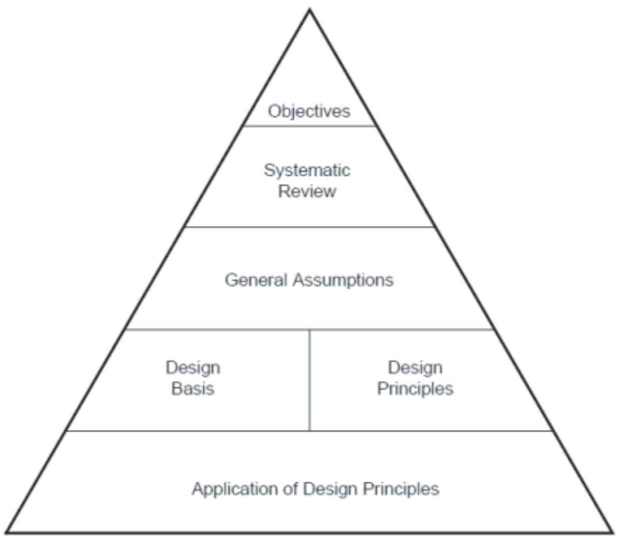

Figure 8 Rules Framework

The General Assumptions specify aspects that are beyond the scope of the Rules, but affect the application and effectiveness of the rules. Typically, these include references to other international regulations and industry standards, e.g. SOLAS and MARPOL. The General Assumptions also includes information on the shared responsibilities of Societies, builders and owners.

The Design Basis specifies the premises that the Design Principles of the Rules are based on, in terms of design parameters and the assumptions about the ship operation.

The Design Principles define the fundamental principles used for the structural requirements in the Rules with respect to loads, structural capacity and assessment criteria. The principles are based on sound engineering practise to provide suitable safeguards against the hazards identified by the systematic review.

The Application of the Design Principles describes how the Design Principles and methods are applied and what criteria are used to demonstrate that the structure meets the Objectives. It includes definition of load and capacity models along with the corresponding acceptance criteria.

(IACS, 2014d) resumes reports describing in detail how the CSR-H complies with the GBS framework.

In (Horn et al., 2013) the philosophy of the "goal based ship construction standards (GBS)" and their implementation in the CSR-H are summarized. In the introduction a general description of the GBS and the declination into 15 functional requirements is described.

Additionally comes a description of the application of GBS in CSR-H, the overview of the CSR-H covering:

- Wave loads
- Equivalent design wave concept
- Fatigue loads
- Corrosion
- Hull girder ultimate strength
- Direct strength analysis
- Buckling (including FE analyses for buckling)
- Fatigue
- Welding
- Ship in operation

There were mentioned the functional aspects not directly covered by the CSR-H.

In (Wenquing et al., 2013) a study of the impact of the CSR-H on the design of tankers is described. The authors conducted a study based on following ship types: 320K VLCC, 163K Suezmax, 115K Aframax, 76K Panamax, 48K MR tankers. A consequence is resumed to the increase of steel weight. In general a weight increase for all type of vessels investigated was found. The analysis is split to show separately the influence of: increased scantlings, minimum thickness requirements, application of load combination in Static +Dynamic conditions for oil cargo tank, the FE analysis covering a larger area of the hull, acceptance and yielding criteria, ultimate buckling capacity of the stiffeners. The lengthening of the design and approval phase was also mentioned.

(Shijian et al., 2013) summarise a comparative study of a corrugated bulkhead of a large product tanker. The study is based on an Aframax 115k DWT vessel. The study contains a rule comparison that is followed by a local scantling analysis. As a next step a direct coarse mesh strength analysis and local fine mesh analysis are discussed. In conclusion a little weight increase has been found for a design according to CSR-H rules. The factors influencing the results are discussed in the conclusions.

5.1.2 Goal Based Standards/Safety Level Approach (GBS/SLA) at IMO

This work started with submissions by different delegations (Germany, 2004) (Denmark et al., 2004b) and (Denmark et al., 2004c). These documents made clear references to extending GBS beyond just structural issues, including all aspects of safety and environmental protections and made clear references to the use of risk assessment (FSA) to justify regulations. For structural issues, (Denmark et al., 2004b) and (Denmark et al., 2004c) refer to Structural Reliability Analysis (SRA).

Over the following years, there were a large number of submissions regarding the GBS/SLA (Safety Level Approach) and IACS even developed an alternative Tier II for the GBS/SLA (IACS, 2006a) and an example of use of SRA according the ALARP principle (IACS, 2006b). These and all other papers on GBS/SLA were not really discussed at IMO, because all available time was spent on the GBS/B&T.

IMO, 2011d is the most updated IMO document containing GBS Guidelines. It is worth noting that the Guidelines are generic, and do not contain a preference for SLA. Actually, it states in paragraph 2 'It should be noted that these Guidelines are generic and where they use phrases such as "required level of safety", this does not imply any preference for a specific technical approach'. As might be understood, this indicates that there is not much agreement at IMO on the way forward.

The GBS/SLA work is now progressed in the Maritime Safety Committee (MSC) in a work group on Goal-based Standards/Safety Level Approach (GBS/SLA) and Formal Safety Assessment (FSA). It is now at least clear that only GBS/SLA is discussed as the way ahead (IMO, 2014b), but there are still discussions on the need to quantify risks.

In the GBS debate over the years there has not been any explicit discussion about sustainability, particularly with the global meaning adopted in the present report. The term is actually not present in the many submitted documents. However, (IMO, 2011e) lists, as above mentioned, safety, security and protection of the marine environment as targets for the action.

The way ahead may be foreseen. The first issue to be dealt with is probably that the FSA Guidelines needs to develop risk criteria also for environmental issues. Currently, this is mentioned in (IMO, 2014b), but the current FSA Guidelines only contain criteria related to oil spill, not to the global heating issues or to the releases to air and sea. By including such criteria, the FSA Guidelines would effectively be changed to general Regulatory Impact Assessment Guidelines. Some of the criteria required, like the external cost of premature deaths due to emissions to air, is already in the FSA Guidelines (QALY Criteria), but this is currently not transferred to criteria needed in IMO policy decisions. IMO typically sets the system border around the ship and would require the criteria as an external cost per ton of air pollutant (e.g. NOx, SOx and PM) or Cost of Averting a Ton of CO_2 equivalent Heating effect (CATCH).

In conclusion it might be stated that there is currently no connection made at IMO between GBS and sustainability, but that it is possible to foresee a development in that direction.

5.2 Regulatory actions implemented at IMO targeting environmental protection

A good overview of recent regulatory and legal developments in the maritime field is given by the United Nations Conference on Trade and Development (UNCTAD) in the review of maritime transport (UN, 2013).

In the following, recent examples of the evolution of the IMO regulatory framework in the direction of the limitation of environmental impact are covered

5.2.1 Energy Efficiency Design Index (EEDI)

Amendments to IMO MARPOL Annex VI regulations for the prevention of air pollution to ships entered into force on January 1st 2013 and introduced the Energy Efficiency Design Index (EEDI) for all new ships and the Ship Efficiency Management Plan (SEEMP) for all ships (IMO, 2011f). As known, the aim of this requirement is to limit the installed power onboard ships and to push an efficient use of it, in view of a reduction in emissions The subject was already reported in (Brunner et al., 2012). Recently, concerns about the effect of these requirements on the manouvrrability of ships in bad weather conditions were taken into account in (IMO, 2014a). In Chapter 6 below a part of the continuing discussion in literature on the theme is recalled.

5.2.2 NO_xSO_x control

Reductions in the emission of nitrogen oxides (NO_X) have been decided by IMO over recent years and inherent requirements are entering into force, as already pointed out in (Brunner et al., 2012). Following MEPC 66, recently amendments have been adopted to MARPOL Annex VI, regulation 13, on Nitrogen Oxides (NO_X), concerning the date for the implementation of "Tier III" standards within emission control areas (ECAs, see § 0 below and http://www.imo.org/MediaCentre/MeetingSummaries/MEPC/Pages/MEPC66.aspx).

Sulphur oxide (SO_X) emission limits were in effect from 1st January 2012, with MARPOL Annex VI establishing SO_X thresholds for marine bunker fuels (UN, 2013) and these thresholds will continue to reduce over time to 0.5% by 2020, subject to a feasibility review in 2018. The EU has mandated that this 0.5% limit will enter force in European waters by 2020.

5.2.3 Emission Control Areas

Emission control areas were created under MARPOL Annex VI *Regulations for the Prevention of Air Pollution from Ships* and defined as "Special Areas". Such "Special Areas" are also possible under MARPOL Annex I *Prevention of Pollution by Oil*, Annex II *Control of Pollution by Noxious Liquid Substances*, Annex IV *Prevention of Pollution by Sewage from Ships*, and Annex V *Prevention of Pollution by Garbage*.

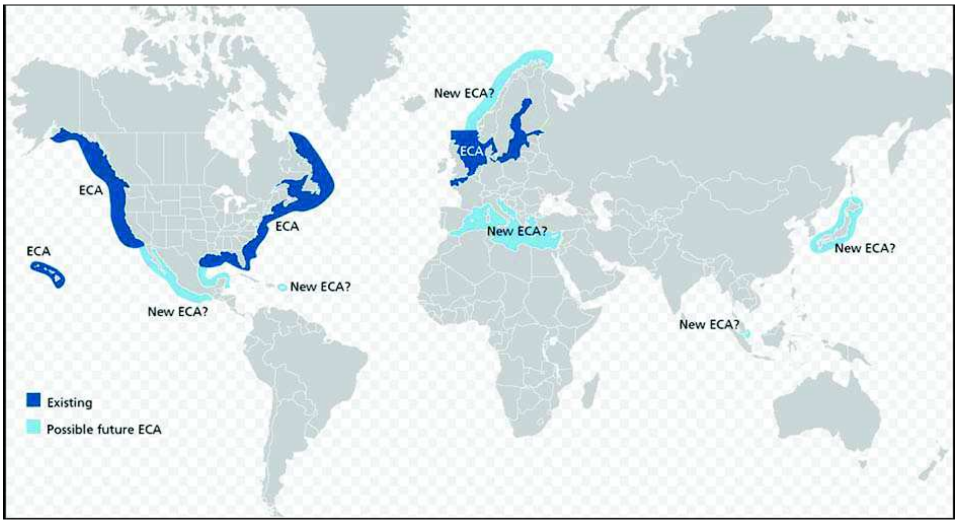

Figure 9. Existing and Possible Future ECAs (DNV, 2011).

"Special Areas" are defined as "certain sea areas in which for technical reasons relating to their oceanographical and ecological condition and to their sea traffic, the adoption of special mandatory methods for the prevention of sea pollution is required. Under the Convention, these special areas are provided with a higher level of protection than other areas of the sea"(International Maritime Organisation, 2014e).

New Emission Control Areas covering SO_X, NO_X, and PM emissions have come into effect for North American (1 August 2012) and United States Caribbean Sea (1 January 2014) areas. These add to the Baltic Sea and North Sea ECAs already in force. Additional potential areas that can become ECAs are highlighted in Figure 9. The considered ECA in North Norway will not be implemented. This decision was based on a CBA along the lines described above.

5.2.4 MARPOL Annex V Prevention of Pollution by Garbage from Ships

On January 1st 2013 entered into force the revised MARPOL Annex V, adopted in July 2011 by MEPC 62 (IMO, 2011g). In March 2012, MEPC 63 adopted also guidelines for the implementation of the Annex (IMO, 2012d) and for the development of garbage management plans (IMO, 2012c).

The view taken by the revised Annex V is that garbage can be just as dangerous to the marine environment as 'classical' pollutants like oil and chemicals. The annex now generally prohibits the discharge of all garbage into the sea, with a few exceptions, listed in specific regulations (n. 4, 5, and 6 of the Annex). The Annex binds Governments to ensure adequate reception facilities at ports and terminals for the reception of garbage.

Special sea areas in a similar way as for the control of emissions are defined according to their oceanographic and ecological conditions and/or to the particular traffic characteristics where the adoption of special mandatory methods for the prevention of marine pollution by garbage is required.

5.2.5 IMO Ship Recycling (The Hong Kong Convention)

The regulatory activity at IMO regarding recycling of ships after reaching the end of their operational lives started at the 44th MEPC session in March 2000 and is not yet finalised. As already mentioned in (Brunner et al., 2012), a major step was the adoption of the Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships (IMO, 2009). This convention aims at ensuring that ships which are being recycled do not pose any unnecessary risks to human health, safety and to the environment.

The convention is not yet in force, still requiring the agreement of 15 states representing 40% of merchant shipping gross tonnage to ratify the convention. In addition the combined annual recycling volume of these states during the preceding 10 years must constitute not less than 3% of the combined merchant shipping tonnage.

A number of application guidelines have been adopted in the meanwhile by MEPC 62, 63, and 64 (IMO, 2011b, IMO, 2011a, IMO, 2012a, IMO, 2012b, IMO, 2012f, IMO, 2012e).

When entering into force, the convention will introduce regulations for the: design, construction, operation and preparation of ships in order to facilitate the safe and environmentally sound recycling of ships without compromising their safety and operational efficiency. Among other provisions, a "Green Passport" for ships was established, containing an inventory of all materials used in the construction of a ship that are potentially hazardous to human health or to the environment.The Convention covers, too, a proper operation of ship recycling facilities and the establishment of a system of certification and reporting requirements enforcing an appropriate application of the provisions for ship recycling.

5.2.6 Pre-normative investigations at IMO in the field of noise radiation into water

In recent years, IMO dealt also with the problem of noise radiation into water by ships. in particular MEPC 58 approved the inclusion of a new high priority item in the work programme of the Committee, on 'noise from commercial shipping and its adverse impact on marine life'.

A Correspondence Group was established to identify and address ways to minimize the underwater noise radiation from commercial shipping operations. The concern was about the short and long-term negative consequences on marine life, especially marine mammals.

An outcome of that work are the later approved 'Guidelines for the reduction of underwater noise from commercial shipping to address adverse impacts on marine life' (IMO, 2014c)

These are non-mandatory guidelines intend to provide general advice to designers, shipbuilders and ship operators about reduction of underwater noise.

It is here noted that the the control of underwater noise radiated by ships has been and is being investigated by EU funded research projects see (SILENV, 2012) (AQUO, 2015) (SONIC, 2015). It is foreseeable that all the above activities will produce in a not far future design and/or operational requirements aimed at reducing this type of impact. Other (non IMO) regulatory actions in the field of ships

5.3 Other (non IMO) regulatory actions in the field of ships

5.3.1 Developments in the Naval Ship Code

Naval platforms are large and complex engineering systems that are typically a product of a long and lengthy development process. They are also generally a unique engineering challenge with considerable limits on the information available at the time that key decisions are made. Whilst the development of goal based standards discussed in section 5 of this report has involved the commercial marine industry, the naval world has also embraced similar concepts and ideas. The development of the Naval Ship Code (NSC) ANEP 77 (NATO, 2014) clearly shows goal based ideas being comprehensively implemented supported by the International Naval Safety Association, whose vision is that "the Naval Ship Code becomes established as a cost-effective goal based standard for naval ship safety benchmarked against statute, and accepted by the global naval community and intergovernmental bodies"(INSA, 2014).

The code is intended to produce an equivalent level of safety to corresponding merchant codes whilst the role of naval ships is such that the safety of the naval ship and embarked personnel may be a secondary consideration (NATO, 2014). The code covers systems such as structure, stability, and fire safety but excludes military specific components. As discussed by (Nappi and Collette, 2013), ANEP 77 does not prescribe specific regulations but rather it is a code for the selection of suitable regulations. In other words, the higher levels and goals are set by the responsible administrations in line with the code and then suitable regulations are developed to achieve these overall goals.

The code was discussed in detail by ISSC Specialist Committee V5 (Ashe et al., 2009) and is not further reviewed in detail here. Recently it has been suggested that the code should be split into two segments with the upper part of the pyramid being the responsibility of the Naval Flag Administrations in setting the goals, and the other segment covering the prescriptive requirements of level 4 via the implementation of relevant Naval Standards or Class Society regulations (Fredriksen, 2013) as shown in Figure 10.

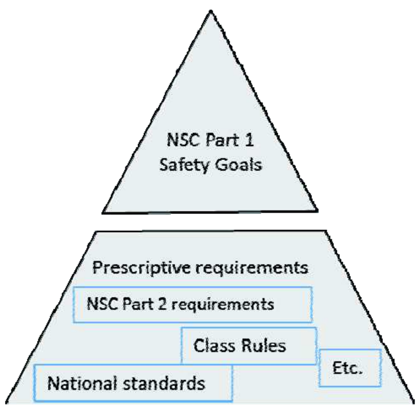

Figure 10. Potential future direction of Naval Code (Fredriksen, 2013).

This splitting of the overall goals from the specific choice of prescriptive requirements enables the standards to be maintained for applicability to a wide range of naval ship types and allows the choice of the best suited standard in each individual design case (Fredriksen, 2013). It introduces the principle of choosing the best suited prescriptive requirements and provides the flexibility to reduce the requirement to commit to single or narrow set of technical solutions. Current ongoing work by INSA is to improve the consistency of the part 1 safety goals by clarifying the goals and the principles behind them themselves in further detail. Framework and guidance for use of the Naval Ship Code certification are also being developed.

5.3.2 Inland vessels

An overall picture of the dimension of inland water transport (IWT) in Europe can be derived by the recent survey by the Central Commission for the Navigation of the Rhine (CCNR, 2014). There, about 8000 dry good vessels and 1,650 tankers are mentioned, with various sizes.

For numbers related to Russia, reference is made to (Egorov, 2014), mentioning for dry cargo about 1200 motor vessels and 4900 barges, for tankers 700 motor vessels and 900 barges and, finally, about 5800 pusher boats. An analysis of the state and age of this fleet is reported in the same paper.

For more than six decades, UNECE Inland Transport Committee (ITC) has promoted the develop of international inland water transport at European level. A recent document exploiting the characteristics and advantages of this transport mode is the White Paper on Efficient and Sustainable Inland Water Transport in Europe (UNECE, 2011b)

UNECE provided a platform for intergovernmental cooperation to facilitate IWT. An important target of UNECE is the development of a unified normative framework at European level.

This is particularly needed as the IWT suffers, even at a European level, from a historical infrastructural, institutional, legal and also technical fragmentation, due to the presence of local institutions (River Commissions: Danube – DC, Rhine – CCNR, Mosel – MC, Sava – SC) providing requirements for their specific river basins on various overlapping subjects.

The Recommendations on Harmonized Europe-Wide Technical Requirements for Inland Navigation Vessels (UNECE, 2011a) establish a Pan-European regime of technical requirements for inland navigation vessels engaged in international transport of goods and passengers. They are a result of Governments efforts, aimed at unifying the divergent regulations in force within different intergovernmental organizations and within individual UNECE member countries. These unified regulations have been brought in line with relevant European Union's legislation and are to facilitate vessels engaged in international transport by inland waterway (see http://www.unece.org).

The Recommendations contain, in particular, strict regulations on limitation of air and water pollution by vessels and on abatement of the noise radiated as well as internationally agreed standards for minimum manning requirements and working and rest hours of crews.

Operational requirements are also contained in the European Code for Inland Waterways-CEVNI (UNECE, 2009)

Another relevant document is the European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN), issued by the Central Commission for the Navigation of the Rhine (CCNR, 2015).

The issues of pollution prevention and waste management are addressed by several UNECE and River Commission instruments, such as special resolutions and relevant provisions of the technical prescriptions for vessels.

For example, on November 1st 2009, the convention on the "Collection, deposit and reception of waste produced during navigation on the Rhine and Inland Waterways" (CDNI) entered into force (CDNI, 2009). Upgrades have been issued in the following years.

The CDNI has been adopted by six countries (Luxembourg, Switzerland, the Netherlands, Belgium, Germany and France) and is applicable over the entire length of the river Rhine and on all inland waterways in Germany, the Netherlands and Belgium, on the international part of the river Moselle in Luxembourg and France. In order to assure the application on the entire geography of the Convention, the respective rules have been transposed into the national law of each Member State so as to become applicable in the conventional network.

The same subject are covered in Res. 21 "Prevention of Pollution of inland Waterways by vessels" (UNECE, 2007) and CEVNI (UNECE, 2009) and following updates, including cooperation with various River Commissions (in particular Sava and Danube)

In 2010 the Russian Federation approved new technical regulations for the safety of Russian IWT objects. These requirements regulate the presence of double bottom and double sides for tankers and vessels transporting dangerous cargoes.

5.3.3 EU Directive on Safety of Offshore Oil and Gas Operations

It is here just mentioned that attention to environment in the Off shore field is shown by the European Union with the adoption of the Directive 2013/30/EU on Safety of Offshore Oil and Gas Operations (EU, 2013) which intends to enhance the safety standards on platforms across European waters whilst minimising potential damage to the environment and the livelihoods of coastal communities.

5.4 Comments on the recent developments in the normative framework

From the review presented in this chapter, some general trends in the development of normative frameworks for the design and operation of ships can be detected.

On one hand, the need for a simplification and systemisation of the general lay out of the Norms is quite diffused even though it could be implemented to a different extent in the different fields. For commercial shipping, the international nature of the activity and the presence of a world wide normative organisation like IMO facilitates the process, while for naval vessels and for inland vessels, this is objectively more difficult due to the particular interests and local characteristics of the activities.

The trend for enlarging the spectrum of implications of shipping activities to include the impact on environment in its various forms is also easily identifiable, with concerns that are oriented both to global effects on planetary scale (GHG emissions) and to more local effects (chemical pollution, waste treatment, noise). For inland water vessels, the local effects show a higher priority, giving the higher proximity with inhabited areas and their specific features.

At IMO level, too, in addition to general requirements set world wide, specific ones are set in 'special areas'.

Requirements at all levels are however still formulated in a prescriptive way, i.e. they force the achievement of specific results on single aspects of the design. In this respect, the present state of the art of the regulatory framework for shipping is not in line with the approach defined in 1,2 and 3 of design for sustainability. As always when dealing with prescriptive requirements formulated independently from each others, the efforts needed to meet the requirements themselves are not globally optimised in a cost-benefit sense. In other words, this type of formulation prevents the possibility of finding the optimal global solutions that could be sought by a rational and holistic approach to the design for sustainability.

6. STUDIES FOCUSSING ON ENVIRONMENTAL IMPACT

The present chapter aims at providing a few references about the recent developments of the scientific and technical framework in which the concept of design for sustainability finds its roots. The focus is on ship design, even though many issues have much more general implications.

6.1 Studies on Green House Gas Emissions

When dealing with the global impact on planetary scale of anthropogenic emissions, very comprehensive and authoritative references are represented by the Assessment Reports by the Intergovernmental Panel on Climate Changes, in particular the latest one (5^{th} one: AR5) with the synthesis report (IPCC, 2014c) and the detailed reports by the three working groups (IPCC, 2013, IPCC, 2014a, IPCC, 2014b).

The AR5 provides an update of knowledge on scientific, technical and socio-economic aspects of climate change. The study analyses the observed changes in the climate, with causes, effects and impacts. It identifies past and recent drivers of climate change linking them to human activities.

The Report concentrates, even more than in previous editions, on the future evolution, identifying possible scenarios for discussing risks, adaptation and in particular mitigation measures to contain the changes.

Among many other findings, a confirmation of an overall possible objective of a limitation of the earth's temperature rise to 2°C, as previously set (IPCC, 2007b) and discussed, see e.g.(den Elzen and Meinshausen, 2006) and a further deepening of the twofold global effect (cooling, but also heating) due to a control of some air pollutants typical of ship emission: (SO2 and NOx: see (IPCC, 2013), chapt. 8). As regards CO_2 emissions from ships, the Third IMO Greenhouse Gas Study (GHG) 2014 (Smith et al., 2014b) has updated the outcomes of the previous edition (Buhaug et al., 2009) with predicted emissions from shipping of 3.1% of annual global CO_2 emissions in 2007 and these are expected to increase by 2050. The work develops a multi-year inventory and future scenarios for the period 2007 – 2050.

This has lead toward significant efforts being proposed, and some implemented, as to how to quantify and reduce the potential impact of shipping and related activities.

Investigations in this area have been carried out by the UK Low Carbon Shipping consortium (Smith et al., 2014a) and the Clean North Sea Shipping consortium (CNSS, 2014).

Fitzgerald et al., 2011 assessed the methodologies for calculating greenhouse gas emissions from international maritime transport through a case study of the imports and exports from New Zealand. This investigation in particular highlighted the potential for differing results when considering emissions calculated from fuel bunkered for international transport and emissions computed on the basis of the actual movement of goods in and out of New Zealand. International policy implications are discussed.

Murphy et al., 2013 discussed that there are numerous initiatives for the assessment of the environmental performance of ships and highlighted that the two most widely used are able to address more than one pollutant of interest. They went on to consider the effectiveness of current and possible future forms of environmental indexing schemes.

6.2 Studies on countermeasures to limit emissions

6.2.1 Slow steaming

Psaraftis and Kontovas, 2010 investigated the implications of various maritime emission reduction policies for maritime logistics exploring the trade-offs between environmental benefits associated with slow steaming and fleet size and the economic attributes such as in-transit inventory holdings.

(Claudepierre et al., 2012) discussed the potential use of ultra-slow ships for CO_2 reduction. This work considered the advantages and disadvantages of slow steaming, in particular in crowded shipping lanes, adverse weather or areas where there may be security concerns, concentrating on determining if available propulsion power, when slow steaming, enabled the safe operation of this ship. This concept was also considered by (Smith et al., 2014a) who highlighted the potential need for more ships to be constructed in order to meet supply chain demand and the emissions from the manufacturing processes may outweigh any potential benefits.

Lindstad et al., 2011 considered the potential reductions in greenhouse gases and cost by shipping at lower speeds for a selection of shipping classes showing that there is a potential for substantial reductions in direct CO_2 emissions from ships.

6.2.2 Scale effects and propulsive improvements

Lindstad et al., 2012 investigated the importance of economies of scale for reducing the levels of greenhouse gas emission from ships through the consideration of the effect of increasing vessel size. This study suggests that replacing the current fleet with larger vessels would result in a reduction in CO_2 emissions.

Molland et al., 2014 reviewed the practical improvements in the propulsive efficiency of future ships. This work investigated the potential design changes and placed them into the context of economic and environmental efficiency.

6.2.3 Discussions of the EEDI concept

The intention of the EEDI is to reduce the installed power on ships, however there is concern as to the unintended consequences of this change potentially in the safe operation of ships. This was discussed in the previous report of this committee (Brunner et al., 2012).

Verhulst et al., 2013 discussed the applicability of EEDI values to small cargo ships concluding that these ship types will require correction factors to the EEDI formulae in order to account for the effects of different operational profiles, class notations, and installed loading gear found on such vessels.

Pundt and Kruger, 2013 reported the development of a methodology to verify the speed of a ship for the EEDI.

Egorov and Kolesnik, 2012 show that Russian new generation river-sea vessels satisfy EEDI requirements.

Longva et al., 2010b reported on the development of a required energy efficiency design index level based on a cost-effectiveness criterion. This work considered how to set the required targets for the EEDI based on a decision criterion of 50 USD per tonne $CO_{2\text{-eq}}$ averted. 11 emmission reduction measures were analysed within this study for a representative ship type with results indicating the potential for a reduction in the required index level of 25–30% in a cost effective manner. It is suggested that as the EEDI only consideres CO_2 emission reductions, there is potential for adverse impacts on other emissions, discharges, safety levels for crew and ship which should be addressed with a total impact analysis.

6.2.4 Studies on control of NO_x and SO_x emissions

CNSS, 2014 reports that any potential delay in the ongoing change over to tier 1 and 2 engines will have a significant impact on the contribution from shipping related activities to global levels of NO_2.

Dinwoodie et al., 2013 used a Delhi study to investigate the perceptions of maritime specialists of the potential changes in maritime oil fright flows to 2050. This study suggests that the effects of local sourcing, new artic seaways, and reduced fossil fuel usage will result in lower oil freight but that the introduction of Emission Control Areas and piracy may result in longer haul lengths as shipping re-routes to reduce the impact of these restrictions.

A similar study investigating the Dry Bulk shipping flows to 2050 was undertaken by (Dinwoodie et al., 2014). This study reported that an expected increased raw material shipping might be offset by reduced haul lengths and that an expected rise in demand for biofuels combined with a reduction in fossil fuels will lead to system based approach to future planning.

6.2.5 Emissions Trading Schemes

Within the European Union (EU), greenhouse gas emissions have been a topic of significant debate for some time. For the aviation sector, the EU has begun to implement an emissions trading scheme (ETS) which aims to limit or “cap” the total amount of certain greenhouse gases which can be emitted within European airspace. This has proven highly controversial and is subject of much international political debate.

A similar scheme has been proposed for the shipping sector within European waters which is the subject of considerable debate. (Smith et al., 2014a) provide an outline of the parallels and differences between such ETS schemes for the aviation and shipping sectors.

6.2.6 Alternative Fuels

A review of future ship powering options was undertaken by the UK Royal Academy of Engineering (2013). This report was prepared by a working group of approximately 45 leading industrialists and academics considered the potential benefits of a range of propulsion options with the aim to reduce the impact on the environment whilst maintaining operational efficiency. Whilst other propulsion options such as LNG, fuel cells, biofuels, and hydrogen are all potentially adoptable, a key conclusion from the report is that the adoption of any alternative propulsion options will be dependent upon the prices of fuels, the impact of present and future legislation, and the potential introduction of carbon taxes. For many of these alternative options, significant research and development challenges remain both in the actual technology development but also in the infrastructure and supply chain required to actually provide them.

Bengtsson, Fridell, and Andersson (2012) investigated the life cycle performance of two alternative pathways to biofuels in the shipping industry by considering the use of bio-diesel and liquefied biogas. Within the context of this life-cycle analysis, it is reported that the use of biogas resulted in potentially better environmental performances that the use of biodiesel, due to a lower overall environmental impact, but that the biodiesel had more infrastructure in place. The study also reported that, although the use of biofuels would have an effect on reducing the global warming impact from shipping, this would be at the expense of greater potential impact from other methods of reduction in environmental impacts, and that the biomass itself may be more cost effectively used in other industries.

7. CONCLUSIONS

In the first three chapters of this report, the general bases of the concept of design for sustainability have been outlined. Such concept seeks a rational approach to decision making in a normative context by pursuing an holistic approach in considering the implications of the regulatory action. This means to account for effects ranging in the probability domain from certain to very rare events, in the time domain from contemporaneity to far future and spanning in different fields (preservation of assets, human health and environment).

Basic tools for probabilistic methods of analysis are available since many years and their adoption in the development of the normative framework at IMO is slowly gaining momentum, as recalled in § 5. In general the use of these methods is growing in the technical and scientific literature in the field of ship construction, as partially reported in §4 and §6.

The discussion about depreciation rates in decision making reported in §3 relates mainly to long term global effects of GHG emissions and is not specific for shipbuilding: concepts and procedures can (and have to) be adopted in line with other fields.

More room seems to be available for quantifying better those aspects of environmental impact that are specific of the maritime sector and may differ significantly in terms of emissions, of effects (or both) in respect to other transport modes and/or human activities.

As remarked in § 5, the normative framework in shipbuilding is still nowadays dominated by prescriptive requirements, whose formulations not necessarily represent the most balanced design solution in respect to sustainability. What is felt to be important for defining rational design criteria for ships, in line with the sustainability target, is to give a proper weight to all the local aspects of the environmental impact: on the marine as well as the atmospheric part of the ambient. This includes chemical emissions, but also f.i. noise radiation in water (as it is done in air for other transportation means and inland vessels). In the atmosphere, specific aspects could include those effects (e.g. PM emissions) which, with the exception of a few sensitive areas, might have a different impact as compared to analogous emissions on land and should therefore be valued accordingly.

Operations like the one carried out in (Korzhenevych et al., 2014) of 'pricing' external costs of transport in general could be carried out in more details for the shipping sector in order to get a more precise picture of the actual societal impact of maritime activities (and of the subdivision into the various components). This would make possible to take more rational normative and design decisions on where allocating resources to enforce sustainability in this sector.

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