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Study on assessment of possible global regulatory measures to reduce greenhouse gas emissions from international shipping

Final Report

CE Delft
March – 2021

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Content

Executive summary

Context of the study

The Paris Agreement commits its signatories to hold the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit it to 1.5°C, amongst others. In order to reach this goal, global greenhouse gas (GHG) emissions should peak as soon as possible and be reduced rapidly to zero as soon as possible in this century.

Partly in response to the Paris Agreement, the International Maritime Organization (IMO) has adopted its Initial Strategy on Reduction of GHG Emissions from Ships. It expresses the ambition to peak GHG emissions from international shipping as soon as possible and to reduce the total annual GHG emissions by at least 50% by 2050 compared to 2008 whilst aiming phasing them out completely as soon as possible in this century.

To reach this ambition, the Strategy acknowledges that alternative fuels and/or energy sources will be required and that their use needs to be supported by policy instruments. The Strategy lists a number of *candidate measures* but does not contain an evaluation of their effectiveness to reach the levels of ambition. It distinguishes between short-, mid-, and long-term measures. The former are to be adopted before 2023; mid-term measures between 2023 and 2030; and long-term measures after 2030.

The Strategy also contains a requirement to assess the impacts of measures on States before their adoption, and a requirement to address disproportionally negative impacts.

Objective of the study

This study aims at informing the forthcoming IMO discussions on mid- and long-term emission reduction measures and their impacts on States, based on a transparent methodology. This is done by identifying the advantages and disadvantages of measures.

The study has started out by developing a long list of all possible measures that are capable of ensuring that the shipping sector phases out its GHG emissions, as called for in the Initial Strategy. It then evaluates these measures on criteria of environmental effectiveness (i.e. the incentive provided to a fuel transition), cost-effectiveness, and predictability. The best-scoring measures have been further developed.

Another objective of the study is to better understand the the possible impacts on States of a measure capable to decarbonise the sector based on a computable general equilibrium model supplemented with case studies. Moreover, the study analyses ways to address disproportionally negative impacts on States.

This study analyses global measures which can be agreed and adopted by the IMO and follow from the Initial IMO Strategy on reduction of GHG emissions from international shipping. Regional measures and the possible interactions between regional measures and global measures are beyond the scope of this study.

Policy measures

The study started with the identification of a longlist of meaningful candidate mid- and long term measures. The longlist included seventeen pricing mechanisms:

- three alternative cap & trade emissions trading schemes (ETS);
- two alternative tax/levy schemes;
- four alternative baseline & credit schemes;
- four alternative standard & penalty; and
- four alternative feebate schemes[1].

Nine of these seventeen measures have already been proposed to/discussed at the IMO. To establish a shortlist of candidate measures to be developed in more detail, assessment criteria have been developed. The most important criterion is that the selected measures are able to result in the decarbonisation of maritime transport. Since other measures are outside of the scope of the study, all measures fulfil this criterion. The study has evaluated the measures from the longlist using the following criteria:

1. Legal aspects.
2. Practical feasibility.
3. Impacts on administrations.
4. Direct impacts from the social perspective.
5. Impacts on maritime sector.
6. Indirect impacts as a consequence of the direct impacts on the maritime sector.
7. Aspects that should be considered when determining the indirect impacts.
8. Criteria to put the potential impacts into perspective.

Based on this multi-criteria assessments, the study identified the best scoring measures plus and developed their design in more detail. Two of the selected measures are standard-based, two of them market-based: a low-GHG fuel standard; an operational GHG intensity standard; a GHG emissions trading scheme; and a GHG emissions tax. Each one will be described in more detail below.

A low-GHG fuel standard sets a limit value for the GHG emissions of a fuel over its life cycle. It could be implemented as a regulation in MARPOL Annex VI, similar to the current regulations on the sulphur content of the fuel. In order to reduce GHG emissions to zero, the limit value would need to follow a trajectory from its current level to zero within an agreed timeframe. Like the other measures discussed below, the low-GHG fuel standard requires accepted ways to establish the lifecycle GHG emissions and agreement on sustainability criteria for fuels and inputs in their production processes. Furthermore, the existing data collection system may need to be improved with additional safeguards against misreporting in order to ensure the integrity of measure.

There are several ways in which the GHG fuel standard can be implemented, which has a bearing on how ships can comply:

- Ships can be required to comply continuously with the standard. This means that they need to use compliant fuels exclusively. When the standard has not yet reached zero, these fuels can be blends of fossil fuels and renewable fuels, or pure renewable fuels, although in that case ships would perform better than the standard.
- Ships can be required to comply with the standard on average within a certain compliance period. This means that they can either use compliant fuels continuously or alternate between renewable and fossil fuels. Depending on the level of the standard is and the fuel consumption of the ship, they might also use renewable fuels for e.g. auxiliary engines and boilers and fossil fuels for the main engine.

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[1] A ship standard combined with a penalty & reward is in the following referred to as feebate scheme.

- Ships can be required to comply with the standard on average within a group of ships. This means that, in addition to the two compliance options mentioned above, a group of ships can comply when some of them sail on overperforming fuels and some of them sail on fuels that do not meet the standard, as long as the average GHG emissions per unit of fuel of the group meets the standard. Group-compliance can be formalised and extended to the entire fleet by issuing credits to ships that use fuels which have GHG emissions that are lower than the standard. These credits could be transferred to ships that use fuels which have GHG emissions over the standard, which can use the credits to compensate for their undercompliance. Although such a system would be administratively more complex than the two requirements mentioned above, it has the advantage of being open for more types of fuels, including zero-carbon fuels, from the beginning of the implementation.

An operational GHG intensity standard sets a limit value for the GHG emissions of a ship per unit of transport work or similar indicator of the value it creates. It could be based on the Carbon Intensity Indicator which is being developed as part of the short-term package of measures in the IMO and thus be implemented as a regulation in MARPOL Annex VI. In order to reduce GHG emissions to zero, the limit value would need to follow a trajectory from its current level to zero within an agreed timeframe. While the starting level would be different for each ship type and in addition depend on the size of a ship, all ships could achieve a zero CII at the same date. Similar to the low-GHG fuel standard, the operational GHG intensity target would require there being an accepted way to establish lifecycle GHG emissions of fuels, in addition to accepted ways to determine the carbon intensity of a ship.

Similar to the fuel standard, there are several ways in which the GHG intensity standard can be implemented, which has a bearing on how ships can comply:

- Ships can be required to comply with the standard on average within a certain compliance period. This means that they need to implement technical and operational energy-efficiency measures as well as choose fuels with a certain GHG intensity in such a way that at the end of the compliance period, the GHG emissions per unit of transport work (or other indicator of the value it creates) do not exceed the applicable limit value.
- Ships can be required to comply with the standard on average within a group of ships. In this case, credits could be granted to ships that overperform, e.g. have lower GHG emissions per tonne-mile than the required standard of the moment. These credits can be surrendered by ships that do not meet the limit value. Ship types which have different units for the CII could probably not trade credits with each other unless equivalency between the units is agreed.

The two standard-based measures described above could also be implemented as **standard-and-penalty schemes**, in which non-compliant ships would need to pay a penalty. The penalty can increase with the severity of the non-compliance and can be set at a level that deters non-compliance (in order to maximise emissions reductions) or at a level that maximises revenues of the penalties.

In a cap-and-trade scheme for maritime GHG emissions ships would be obliged to annually submit allowances for each unit of CO_2 emitted, with a limited total amount of allowances becoming annually available for the sector, gradually declining over time. The allowances would be auctioned off and/or (partially) be allocated for free to the ships with the possibility to trade the allowances on a secondary market. Ships with low CO_2 emissions would have to buy fewer allowances or could sell some of their allowances to ships with relatively expensive CO_2 abatement options. The cap for international shipping could be specified in MARPOL Annex VI together with the requirement that ships need to hand in allowances. The allocation of allowances to ships could be organised either by IMO or by Flag States. In the latter case, the IMO would need to decide on how to distribute allowances over States.

Unless the system allows for using offsets from other sectors, a cap-and-trade system can ensure a full decarbonisation of the shipping sector.

As the number of allowances decreases, their value will increase. Because allowances have value, ships are incentivised to reduce their emissions up to the point where reducing them more exceeds the value of the allowance. At some point, the value of the allowances becomes sufficiently high for renewable fuels, for which no allowances need to be handed in, to become cheaper to use than fossil fuels, which do require allowances.

A GHG tax or levy would require ships to regularly pay a fee based on the quantity of GHG emissions by that ship. The tax could either be set directly at a level that renders the use of fossil fuels uneconomical or be gradually increased to that level so that renewable fuels, over which no taxes need to be paid, become cheaper to use than fossil fuels. The tax could be liable to the Flag State, to the IMO or to an organisation designated by the IMO to collect the tax and disburse the revenues. Although a tax obligation could in principle be included in MARPOL provided that there is sufficient support to do so, a new Annex to MARPOL or a new convention could also be considered.

Comparison of measures

The four policy measures described above all have the ability to decarbonise the sector. Two of them directly incentivise all options to reduce emissions, be they technical, operational or a change in fuels. The reason is that in a tax system and an emissions trading scheme, each reduction in emissions results in lower compliance costs.
The operational GHG intensity standard, if applied on a per-ship basis, only rewards emissions reductions up to the standard. However, when pooled compliance is allowed through a baseline-and-credit trading scheme or otherwise, all emission reductions are incentivised. The fuel standard, if applied on a per-ship basis, only directly incentivises reductions in fuel-related emissions up to reaching the standard. If applied on a fleet-wide basis, all fuel-related reductions are incentivised and indirectly also all measures that result in reducing the amount of fuel used through technical or operational means. The standard and penalty systems only reward emission reductions up to the standard. Some of these measures could also eventually combined e.g. a standard on low-GHG fuel to progressively accelerate the demand for renewable and low-GHG fuels together with a cap-and-trade scheme to cap the overall amount of emissions of the sector.

The ability to support a wide range of mitigation measures has a direct impact on the cost-effectiveness of a measure because, apart from administrative costs, the larger the set of options to comply, the lower the costs. Hence, the emissions tax, the emissions trading scheme, and the operational GHG intensity standard, if applied on a fleet-wide basis, all have a similar cost-effectiveness. The low-GHG fuel standard lags a little behind.

In contrast, the incentive for fuel-related innovation is the largest in the low-GHG fuel standard because it rewards the use of low- or zero-GHG fuels from the start, and not, as the other measures do, only when the cheaper options to reduce emissions have been exhausted.

The tax stands out for having the highest certainty about the compliance costs because the costs per unit of emissions are specified in the regulation. An emissions trading scheme offers most certainty about the emissions pathway, followed by the low-GHG fuel standard and the operational GHG intensity standard, while the tax has the lowest certainty.

Table 1 - Comparison of mid-term measures

Measure		Range of reduction options directly incentivized	Incentive uptake of low/zero fossil carbon fuels at relative early stage	Certainty with which the desired emissions pathway can be followed	Administrative complexity	Integration in existing IMO instruments
Low-GHG Fuel Standard	Per ship	Reduction of lifecycle GHG emissions of fuels up to the standard (indirectly, through higher fuel prices: measures that reduce fuel use)	Incentive for drop-in fuels from the start, possibly increasing to auxiliary engines and boilers, finally the main engine	The actual pathway will be a combination of the regulated GHG intensity of the fuels and the market-driven amount of fuel used. The latter depends on the activity of the shipping sector	Fuel LCA emissions certification DCS with strengthened verification	Compatible with MARPOL Annex VI. Requires amendments on: Fuel LCA emissions calculation and verification
	Fleetwide	Reduction of lifecycle GHG emissions of fuels (indirectly, through higher fuel process: measures that reduce fuel use)	Incentive for all low- and zero-GHG fuels from the start of the implementation		Fuel LCA emissions certification DCS with strengthened verification Procedure for issuing credits Credit registry	Fuel GHG standard Credit issuance and use
Operational GHG intensity standard	Per ship	All measures that reduce emissions up to the standard	Low- and zero-carbon fuels are incentivised when the standard cannot be reached by cheaper options	The actual pathway will be a combination of the regulated operational GHG intensity and the market-driven activity of the shipping sector	Operational efficiency reference lines Fuel LCA emissions certification DCS with strengthened verification	Compatible with MARPOL Annex VI. Requires amendments on: Fuel LCA emissions calculation and verification Operational GHG emissions calculation and verification Operational GHG intensity standard
	Fleetwide	All measures that reduce emissions	Low- and zero-carbon fuels are incentivised when cheaper options to improve operational GHG intensity are exhausted		Operational efficiency reference lines Fuel LCA emissions certification DCS with strengthened verification Procedure for issuing credits	

Measure	Range of reduction options directly incentivized	Incentive uptake of low/zero fossil carbon fuels at relative early stage	Certainty with which the desired emissions pathway can be followed	Administrative complexity	Integration in existing IMO instruments
				Credit registry	Credit issuance and use
Cap and trade	All measures that reduce emissions	Low- and zero-carbon fuels are incentivised when cheaper options to reduce emissions are exhausted	The cap prescribes the desired pathway and the policy, if well enforced, ensures that the pathway is realised	DCS with strengthened verification Procedure for allocating allowances Allowance registry	Possibly compatible with MARPOL Annex VI. Requires amendments on: Fuel LCA emissions calculation and verification Allowance allocation and use for compliance
GHG tax	All measures that reduce emissions	Low- and zero-carbon fuels are incentivised when the tax is sufficiently high to make them competitive with fossil fuels	The actual pathway depends on the reaction of the shipping sector to the incentive of the GHG tax	DCS with strengthened verification Procedure for collecting taxes Procedure for disbursing revenues	Possibly MARPOL Annex VI, or new Annex or new Convention

Methods to assess impacts on States

The Initial Strategy specifies that the impacts of measures on States need to be assessed before adoption of the measure and that disproportionally negative impacts should be addressed, as appropriate. The Strategy mentions the following impacts specifically:

- geographic remoteness of and connectivity to main markets;
- cargo value and type;
- transport dependency;
- transport costs;
- food security;
- disaster response;
- cost-effectiveness; and
- socio-economic progress and development.

This study has undertaken to develop indicators for each of these categories so that they can be used in impact assessments. These are summarised in Table 2.

Table 2 - Summary of indicators for each category that need to be considered in impact assessment

Impact	Indicators
Geographic remoteness of and connectivity to main markets	Remoteness: 1. The market share of country's x trade partners, i.e. the sum of import and export volume of the country from and to their trading partners. 2. The transport costs (whenever data is available) or travel time between country x to all of its markets combined with value of time of the cargo. Connectivity: UNCTAD's Liner Shipping Connectivity Index (LSCI), in addition to transit time and number of transhipment for non-containerised cargoes.
Cargo value and type	1. The value of time (VoT) of different cargo types and their travel duration. 2. The ad-valorem rate of different cargo types.
Transport dependency	1. The shares of maritime export and import in a country's GDP. 2. The costs and availability of other substitute modes to transport goods from and to the States.
Transport costs	1. Actual transport costs, e.g. CIF/FOB differences; transport cost proxies like: a Maritime transport distance between origin and destination. b Cost of logistic operations such as port handling and transshipment costs. c Average ship running costs, which is explicitly broken down by capital and operational expenditures that include ship fuel costs/bunkering. d Commodities weights and values.

Impact	Indicators
	e Travel time between origin and destination, which includes transshipment and ship dwell time, and hinterland travel time. f Trade balance of origin and destination country pairs. g Socio-economic indicators such as GDP, GDP per capita of both importing and exporting countries. h Infrastructure quality at origin and destination. i Value of time of commodity ¥ the equivalent monetary value for each time unit spent by the commodity during transport between origin and destination.
Food security	1. The share of food consumption in the average household expenditure of States. 2. The share of food imports in total food consumption.
Disaster response	1. The share of imported commodities crucial for providing disaster relief that is supported by maritime transport in the total economy of the States (GDP). 2. The modal share of maritime mode to transport goods that are crucial to mitigate the impacts of a disaster such as food, medicines, clothing, first-aid kits, tents, and emergency power supplies. 3. The total logistics costs to supply the demand for goods and services in the occurrence of a disaster.
Cost-effectiveness	1. Ratio between GDP change and the total GHG emissions reduced at the global level. 2. Ratio between changes in commodities trade volumes and the total GHG emissions reduced from export and import activities.
Socio-economic progress and development	1. Gross Domestic Product (GDP). 2. Welfare. 3. Employment. 4. Poverty level. 5. Government spending on public services (e.g. health, education, transport). 6. Gender impacts (income levels of different gender).

Impacts of measures

This study establishes that Computational General Equilibrium (CGE) models can provide useful insights into a number of the types of impact produced by GHG reducing measures.
Estimations of impacts are derived from a specific CGE model: GTAP, a multiregion, multisector, computable general equilibrium model, with perfect competition and constant returns to scale, which is widely used by the European Commission, the IPCC, OECD, WTO and other institutions. Due to modelling constraints, the results are derived for a sample of individual countries, and with a particular focus on providing results for SIDS and LDC economies.

The report has modelled the impacts of a situation where 50% of the fuels used by maritime transport are zero-carbon fuels (power-to-x fuels). Because of the uncertainty about the costs of those fuels, a high and a low-cost estimate have been modelled.

The modelling results show the impact of the fuel transition independent of the policy measure adopted. In case revenue-raising policy measures are implemented and a share of the revenue is used outside of the shipping sector, the cost increase for the industry will be lower and the impacts will be larger.

The results show that the impacts created by a generalised GHG reducing policy are typically much less than a tenth of a percent for most countries and regions, although they vary across different types of economy. The reason that the impacts are small are that imports and exports often constitute a small share of GDP, and that changes in import and export values are often partly offset by changes in domestic production and consumption and investments. High income economies show diverse results: some have net positive impacts and others net negative. Middle income and emerging economies studied had predominantly net positive impacts. In contrast, SIDS and LDCs often had negative impacts (in 20 out of 27 economies studied), and relatively the largest net negative impact of up to -3% of GDP in exceptional cases.

Further insights on how impacts are experienced by different economies are presented including using disaggregated results by sector from the GTAP model for two emerging economies India and Brazil. These detailed results show that whilst the overall impact on an economy may be small (+0.01 - +0.02% of GDP for Brazil, depending on the carbon price, and +0.001 to 0.002% for India), the structure of the economy changes as some sectors grow and others contract. Some sectors benefit from import substitution, while the international competitiveness of other sectors changes, sometimes positively, in other cases negatively.

Pacific SIDS generally have poor quality modelling inputs and therefore the results of modelling are less accurate. The potential impacts on these States are further discussed qualitatively. Many of this region's impacts are expected to be indicative of those experienced by other SIDS economies and are related to high dependency on maritime transport for the many goods that are imported (including of energy commodities which then further cascade through to increased costs of inter-regional and domestic transport). The Pacific SIDS are also highly dependent on shipping for disaster response, and face an impact on their ability to respond if GHG policy on international shipping reduces volumes and frequency of shipping. This impact only increases as climate change effects are increasingly experienced.

Addressing disproportionally negative impacts

The Initial Strategy states that disproportionally negative impacts on States should be addressed as appropriate.

This study identifies several ways to address disproportionally negative impacts which can be grouped into two categories:

1. Exemptions or differentiation (applicable to all measures). They could either be route-based, e.g. to address impacts on specific states; cargo-based, e.g. to address specific types of impacts such as impacts on food security and disaster response; vessel-based, e.g. to address impacts on States emanating from an old fleet or a fleet with small vessels; or time-based, e.g. a gradual phase-in to allow States to prepare longer for a certain policy.
2. Revenue use (applicable only to measures that raise revenues). Policies that raise revenue could apply it on capacity building; investment in shipping services; investment in port and hinterland infrastructure; unconditional financial support; or climate-related support.

Revenue use has two advantages over the first category which both stem from the assumption that the revenue-generating policies would put the same requirements on all ships. If that is the case, there is no risk of carbon leakage within the shipping sector because there will be no benefit in changing routes, cargoes or vessels in order to avoid the costs flowing from the policy. In addition, there is no dilution of the incentive for innovation which would occur if some ships or routes would be exempted.

However, both raising revenues and deciding on how they should be used could be politically difficult.

Among the possible options to redistribute the revenues accumulated from a GHG reduction policy, we consider investment in climate fund, and port and hinterland infrastructure as the most promising measures. They both have high potential in preventing carbon leakage and negating the negative impacts on States. Hence, to draw on the strengths of both measures, the revenues generated from a policy measure can be reinvested for climate fund and targeted port-hinterland infrastructure development whenever possible.

Note that this analysis does not take the ease of reaching agreement amongst States into account as this is impossible to assess when states have refrained from expressing preferences for either option at the MEPC. Note also that the benefits of revenue use would be severely diminished if it is combined with exemptions.

Synthèse

Contexte de l'étude

L'accord de Paris engage ses signataires à contenir l'élévation de la température moyenne de la planète nettement en dessous de 2°C par rapport aux niveaux préindustriels et à poursuivre les efforts pour la limiter à 1,5°C, entre autres. Pour atteindre cet objectif, les émissions mondiales de gaz à effet de serre (GES) devraient culminer dès que possible et être ramenées rapidement à zéro dès que possible au cours de ce siècle.

En partie en réponse à l'accord de Paris, l'Organisation maritime internationale (OMI) a adopté sa stratégie initiale de réduction des émissions de gaz à effet de serre provenant des navires. Il exprime l'ambition de porter au plus vite les émissions de gaz à effet de serre provenant du transport maritime international et de réduire les émissions annuelles totales de gaz à effet de serre d'au moins 50% d'ici à 2050 par rapport aux niveaux de 2008, tout en s'efforçant de les éliminer complètement dès que possible au cours de ce siècle.

Pour atteindre cet objectif, la stratégie reconnaît que des carburants de substitution et/ou des sources d'énergie de substitution seront nécessaires et que leur utilisation doit être soutenue par des instruments stratégiques. La stratégie énumère un certain nombre demesures candidates, mais ne contient pas d'évaluation de leur efficacité pour atteindre les niveaux d'ambition. Elle établit une distinction entre les mesures à court, moyen et long terme. Les premiers doivent être adoptés avant 2023; mesures à moyen terme entre 2023 et 2030; et des mesures à long terme après 2030.

La stratégie prévoit également une obligation d'évaluer les incidences des mesures sur les États avant leur adoption, ainsi qu'une obligation de traiter les incidences négatives de manière disproportionnée.

Objectif de l'étude

Cette étude vise à éclairer les prochaines discussions de l'OMI sur les mesures de réduction des émissions à moyen et à long terme et leurs incidences sur les États, sur la base d'une méthodologie transparente. Pour ce faire, il convient d'identifier les avantages et les inconvénients des mesures.

L'étude a commencé par l'élaboration d'une longue liste de toutes les mesures possibles susceptibles de garantir que le secteur du transport maritime élimine progressivement ses émissions de gaz àeffet de serre, comme le préconise la stratégie initiale. Elle évalue ensuite ces mesures sur la base de critères d'efficacité environnementale (c'est-à-dire l'incitation à une transition énergétique), de rentabilité et de prévisibilité. Les mesures les mieux notées ont été développées.

Un autre objectif de l'étude est de mieux comprendre les incidences possibles sur les États d'une mesure capable de décarboner le secteur sur la base d'un modèle d'équilibre général calculable complété par des études de cas. En outre, l'étude analyse les moyens de traiter de manière disproportionnée les incidences négatives sur les États.

Cette étude analyse les mesures mondiales qui peuvent être approuvées et adoptées par l'OMI et qui découlent de la stratégie initiale de l'OMI sur la réduction des émissions de gaz à effet de serre provenant du transport maritime international. Les mesures régionales et les interactions possibles entre les mesures régionales et les mesures mondiales ne relèvent pas du champ d'application de la présente étude.

Mesures politiques

L'étude a commencé par l'établissement d'une longue liste de mesures significatives à moyen et à long terme. La longue liste comprenait dix-sept mécanismes de tarification:

- trois autres plafonds & systèmes d'échange de quotas d'émission (SEQE);
- deux régimes fiscaux/prélèvements alternatifs;
- quatre régimes de référence alternatifs & crédit;
- quatre normes alternatives & sanction; ainsi que
- quatre régimes alternatifs de redevances[2].

Neuf de ces dix-sept mesures ont déjà été proposées à l'OMI/examinées à ce sujet. Afin d'établir une liste restreinte de mesures candidates à développer plus en détail, des critères d'évaluation ont été élaborés. Le critère le plus important est que les mesures sélectionnées permettent de décarboner le transport maritime. Étant donné que d'autres mesures ne relèvent pas du champ d'application de l'étude, toutes les mesures satisfont à ce critère. L'étude a évalué les mesures de la liste longue sur la base des critères suivants:

1. Aspects juridiques.
2. Faisabilité pratique.
3. Incidences sur les administrations.
4. Incidences directes d'un point de vue social.
5. Incidences sur le secteur maritime.
6. Incidences indirectes découlant des incidences directes sur le secteur maritime.
7. Aspects à prendre en considération lors de la détermination des incidences indirectes.
8. Critères permettant de mettre en perspective les incidences potentielles.

Sur la base de ces évaluations multicritères, l'étude a identifié les meilleures mesures de notation et a développé leur conception de manière plus détaillée. Deux des mesures sélectionnées sont fondées sur des normes, dont deux sont fondées sur le marché: une norme relative aux carburants à faible taux d'émission de gaz à effet de serre; une norme d'intensité de GHG opérationnelle; un système d'échange de droits d'émission de gaz à effet de serre; et une taxe sur les émissions de gaz à effet de serre.
Chacun d'entre eux sera décrit plus en détail ci-dessous.

Une**norme relative aux carburants à** faible teneur en gaz à effet de serrefixe une valeur limite pour les émissions de gaz à effet de serre d'un carburant tout au long de son cycle de vie. Il pourrait être mis en œuvre en tant que règlement dans l'annexe VI de la convention MARPOL, à l'instar de la réglementation actuelle sur la teneur en soufre du carburant. Pour réduire les émissions de GES à zéro, la valeur limite devrait suivre une trajectoire allant de son niveau actuel à zéro dans un délai convenu. À l'instar des autres mesures examinées ci-dessous, la norme relative aux carburants à faible teneur en gaz à effet de serre requiert des moyens acceptés pour établir les émissions de GES tout au long du cycle de vie et un accord sur les critères de durabilité pour les carburants et les intrants utilisés dans leurs processus de production. En outre, il pourrait être nécessaire d'améliorer le système de collecte de données existant en prévoyant des garanties supplémentaires contre les déclarations erronées afin de garantir l'intégrité de la mesure.

Il existe plusieurs manières de mettre en œuvre la norme relative aux carburants à effet de serre, ce qui a une incidence sur la manière dont les navires peuvent se conformer:

- Les navires peuvent être tenus de satisfaire en permanence à la norme. Cela signifie qu'ils doivent utiliser exclusivement des carburants conformes. Lorsque la norme n'a pas encore atteint la valeur zéro, ces combustibles peuvent être des mélanges de combustibles fossiles et de combustibles renouvelables, ou de combustibles purement renouvelables, bien que dans ce cas, les navires

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Une norme de navire associée à une pénalité & récompense est désignée ci-après sous le nom de «feebate scheme».

obtiendraient de meilleurs résultats que la norme.

- Les navires peuvent être tenus de se conformer à la norme en moyenne dans un certain délai. Cela signifie qu'ils peuvent soit utiliser en continu des combustibles conformes, soit alterner entre les carburants renouvelables et les combustibles fossiles. En fonction du niveau de la norme et de la consommation de carburant du navire, ils peuvent également utiliser des carburants renouvelables, par exemple pour les moteurs auxiliaires et les chaudières et les combustibles fossiles pour le moteur principal.
- Les navires peuvent être tenus de respecter la norme en moyenne au sein d'un groupe de navires. Cela signifie qu'en plus des deux options de mise en conformité susmentionnées, un groupe de navires peut se conformer lorsque certains naviguent sur des combustibles surperformants et que d'autres naviguent sur des carburants qui ne satisfont pas à la norme, pour autant que les émissions moyennes de GES par unité de combustible du groupe soient conformes à la norme. La conformité des groupements peut être formalisée et étendue à l'ensemble de la flotte en accordant des crédits aux navires utilisant des combustibles dont les émissions de gaz à effet de serre sont inférieures à la norme. Ces crédits pourraient être transférés à des navires utilisant des combustibles dont les émissions de gaz à effet de serre dépassent la norme, qui peuvent les utiliser pour compenser leur non-conformité. Bien qu'un tel système soit administrativement plus complexe que les deux exigences susmentionnées, il présente l'avantage d'être ouvert à un plus grand nombre de types de carburants, y compris les carburants à émissions nulles de carbone, dès le début de la mise en œuvre.

Une norme d'intensité de GES opérationnelle fixe une valeur limite pour les émissions de gaz à effet de serre d'un navire par unité de transport ou indicateur similaire de la valeur qu'il crée. Il pourrait s'appuyer sur l'indicateur d'intensité de carbone qui est en cours d'élaboration dans le cadre du train de mesuresà court terme de l'OMI et donc être mis en œuvre en tant que règle dans l'annexe VI de la convention MARPOL.Pour réduire les émissions de GES à zéro, la valeur limite devrait suivre une trajectoire allant de son niveau actuel à zéro dans un délai convenu. Alors que le niveau de départ serait différent pour chaque type de navire et dépendrait en outre de la taille d'un navire, tous les navires pourraient atteindre une CII nulle à la même date. À l'instar de la norme relative aux carburants à faibles émissions de gaz à effet de serre, l'objectif d'intensité de GES opérationnel exigerait qu'il existe un moyen accepté d'établir les émissions de GES des carburants tout au long du cycle de vie, en plus des moyens acceptés de déterminer l'intensité de carbone d'un navire.

À l'instar de la norme de combustible, il existe plusieurs façons de mettre en œuvre la norme d'intensité de gaz à effet de serre, ce qui a une incidence sur la manière dont les navires peuvent se conformer:

- Les navires peuvent être tenus de se conformer à la norme en moyenne dans un certain délai. Cela signifie qu'ils doivent mettre en œuvre des mesures techniques et opérationnelles en matière d'efficacité énergétique et choisir des carburants ayant une certaine intensité de GES de telle sorte qu'à la fin de la période de mise en conformité, les émissions de GES par unité de transport (ou tout autre indicateur de la valeur qu'elle crée) ne dépassent pas la valeur limite applicable.
- Les navires peuvent être tenus de respecter la norme en moyenne au sein d'un groupe de navires. Dans ce cas, des crédits pourraient être accordés aux navires dont les performances sont supérieures, par exemple les émissions de GES par tonne-mile inférieures à la norme requise pour le moment. Ces crédits peuvent être restitués par des navires qui ne respectent pas la valeur limite. Les types de navires ayant des unités différentes pour le CII ne pourraient probablement pas échanger des crédits entre eux, à moins que l'équivalence entre les unités ne soit convenue.

Les deux mesures normalisées décrites ci-dessus pourraient également être mises en œuvre sous la forme de**régimes standard**et de sanctions, dans le cadre desquels les navires non conformes devraient payer une pénalité. La sanction peut augmenter avec la gravité du non-respect et peut être fixée à un niveau qui dissuade le non-respect (afin de maximiser les réductions d'émissions) ou à un niveau qui maximise les recettes des sanctions.

Dans un système de plafonnement et d'échange pour les émissions de gazà effet de serre dans le secteur maritime**, les navires seraient tenus de présenter chaque année des quotas pour chaque unité de CO_2** émise, avec une quantité totale limitée de quotas disponibles chaque année pour le secteur, qui diminuerait progressivement au fil du temps.
Lesquotas seraient mis aux enchères et/ou (partiellement) alloués à titre gratuit aux navires, avec la possibilité de les échanger sur un marché secondaire. Les navires dont lesémissions de CO_2 sont faibles devraient acheter moins de quotas ou pourraient vendre une partie de leurs quotas à des navires dont les options de réduction du CO_2 sont relativement coûteuses.Le plafond applicable au transport maritime international pourrait être précisé à l'annexe VI de la convention MARPOL, de même que l'obligation pour les navires de disposer de quotas. L'allocation de quotas aux navires pourrait être organisée soit par l'OMI, soit par les États du pavillon. Dans ce dernier cas, l'OMI devrait décider de la répartition des quotas entre les États.
À moins que le système ne permette d'utiliser des compensations provenant d'autres secteurs, un système de plafonnement et d'échange peut garantir une décarbonation totale du secteur du transport maritime.

Àmesure que le nombre de quotas diminue, leur valeur augmentera. En raison de la valeur des quotas, les navires sont incités à réduire leurs émissions jusqu'à ce que leur réduction dépasse la valeur du quota. À un moment donné, la valeur des quotas devient suffisamment élevée pour que les carburants renouvelables, pour lesquels aucun quota ne doit être versé, deviennent moins coûteux à utiliser que les combustibles fossiles, qui nécessitent des quotas.

Une taxe ou une taxe sur les GES imposerait aux navires de payer régulièrement une redevance en fonction de la quantité d'émissions de GES de ce navire. La taxe pourrait soit être fixée directement à un niveau qui rend l'utilisation des combustibles fossiles non rentable, soit être progressivement portée à ce niveau, de sorte que les carburants renouvelables, sur lesquels aucune taxe ne doit être payée, deviennent moins coûteux à utiliser que les combustibles fossiles. La taxe pourrait être soumise à l'État du pavillon, à l'OMI ou à une organisation désignée par l'OMI pour percevoir la taxe et verser les recettes. Bien qu'une obligation fiscale puisse en principe être incluse dans MARPOL à condition qu'il y ait un soutien suffisant à cette fin, une nouvelle annexe de la convention MARPOL ou une nouvelle convention pourraient également être envisagées.

Comparaison des mesures

Les quatre mesures décrites ci-dessus ont toutes la capacité de décarboniser le secteur. Deux d'entre elles incitent directement toutes les options à réduire les émissions, qu'elles soient techniques, opérationnelles ou de modification des carburants. La raison en est que, dans un système fiscal et un système d'échange de quotas d'émission, chaque réduction des émissions entraîne une baisse des coûts de mise en conformité.
La norme d'intensité de GES opérationnelle, si elle est appliquée par navire, ne récompense que les réductions d'émissions jusqu'à la norme. Toutefois, lorsque la conformité groupée est autorisée par un système d'échange de base et de crédit ou autrement, toutes les réductions d'émissions sont encouragées. La norme relative aux carburants, si elle est appliquée par navire, n'encourage directement la réduction des émissions liées au carburant que jusqu'à ce qu'elle atteigne la norme. Si elles sont appliquées à l'échelle de la flotte, toutes les réductions liées au carburant sont encouragées, ainsi que, indirectement, toutes les mesures qui ont pour effet de réduire la quantité de carburant utilisée par des moyens techniques ou opérationnels. Les systèmes standard et de sanctions ne récompensent que les réductions d'émissions jusqu'à la norme. Certaines de ces mesures pourraient également, à terme, combiner, par exemple, une norme sur les carburants à faible taux d'émission de gaz à effet de serre afin d'accélérer progressivement la demande de carburants renouvelables et à faibles émissions de gaz à effet de serre, ainsi qu'un système de plafonnement et d'échange visant à plafonner la quantité globale d'émissions du secteur.

La capacité de soutenir un large éventail de mesures d’atténuation a une incidence directe sur le rapport coût-efficacité d’une mesure, car, outre les coûts administratifs, plus la série d’options à mettre en conformité est importante, plus les coûts sont faibles. Par conséquent, la taxe sur les émissions, le système d’échange de quotas d’émission et la norme opérationnelle d’intensité de gaz à effet de serre, s’ils sont appliqués à l’ensemble du parc, présentent tous un rapport coût-efficacité similaire. La norme relative aux carburants à faible taux d’émission de gaz à effet de serre accuse un léger retard.

En revanche, l’incitation à l’innovation en matière de carburants est la plus importante dans la norme relative aux carburants à faible taux d’émission de gaz à effet de serre, car elle récompense dès le départ l’utilisation de carburants à faible ou zéro émission de gaz à effet de serre, et non, comme le font les autres mesures, uniquement lorsque les options moins coûteuses de réduction des émissions ont été épuisées.

La taxese distingue par la plus grande certitude quant aux coûts de mise en conformité, car les coûts par unité d’émissions sont précisés dans le règlement. Un système d’échange de quotas d’émission offre la plus grande certitude quant à la trajectoire des émissions, suivie par la norme relative aux carburants à faibles émissions de gaz à effet de serre et la norme d’intensité de GES opérationnelle, tandis que la taxe est la plus faible.

Tableau 1 — Comparaison des mesures à moyen terme

Mesure		Éventail d'options de réduction directement incitatives	Incitation à l'adoption de combustibles fossiles à faible ou zéro carbone au stade relativement précoce	Certitude avec laquelle la trajectoire d'émissions souhaitée peut être suivie	Administratives complexité	Intégration dans les instruments existants de l'OMI
Faibles émissions de gaz à effet de serre Carburant Norme	Par navire	Réduction des émissions de GES sur l'ensemble du cycle de vie des carburants jusqu'à la norme (indirectement, grâce à une hausse des prix des carburants: mesures visant à réduire la consommation de carburant)	Incitation à la pénétration des combustibles dès le départ, en augmentant éventuellement les moteurs auxiliaires et les chaudières, et enfin le moteur principal	Le parcours réel sera une combinaison de l'intensité régulée du GHG des carburants et de la quantité de carburant utilisée déterminée par le marché. Ce dernier dépend:	Certification de l'ACV carburant en matière d'émissions DCS avec vérification renforcée	Compatible avec l'annexe VI de la convention MARPOL.Nécessite des modifications concernant: Calcul et vérification des émissions de l'ACV carburant
	Fleetwide	Réduction des émissions de GES des carburants tout au long de leur cycle de vie (indirectement, grâce à une augmentation du processus énergétique: mesures visant à réduire la consommation de carburant)	Incitation pour tous les carburants à faible ou zéro émission de gaz à effet de serre dès le début de la mise en œuvre	l'activité du secteur du transport maritime	Certification de l'ACV carburant en matière d'émissions DCS avec vérification renforcée Procédure d'octroi de crédits Registre des crédits	Norme relative aux gaz à effet de serre des carburants Émission de crédit et utilisation
Opérationnel GES — intensité norme	Par navire	Toutes les mesures visant à réduire les émissions jusqu'à la norme	Les carburants à faible teneur en carbone et les carburants à émissions nulles sont encouragés lorsque la norme ne peut être atteinte par des options moins coûteuses	Le parcours réel sera une combinaison de l'intensité opérationnelle régulée du GHG et de l'activité axée sur le marché.	Lignes de référence en matière d'efficacité opérationnelle Certification de l'ACV carburant en matière d'émissions DCS avec vérification renforcée	Compatible avec l'annexe VI de la convention MARPOL.Nécessite des modifications concernant: Calcul des émissions de l'ACV carburant et
	Fleetwide	Toutes les mesures visant à réduire les	Les carburants à faible teneur en carbone et les	du secteur du transport maritime	Lignes de référence en matière d'efficacité	Vérification Norme d'intensité GGH

Mesure	Éventail d'options de réduction directement incitatives	Incitation à l'adoption de combustibles fossiles à faible ou zéro carbone au stade relativement précoce	Certitude avec laquelle la trajectoire d'émissions souhaitée peut être suivie	Administratives complexité	Intégration dans les instruments existants de l'OMI
	émissions	carburants à émissions nulles sont encouragés lorsque des solutions moins coûteuses pour améliorer l'intensité opérationnelle des gaz à effet de serre sont épuisées		opérationnelle Certification de l'ACV carburant en matière d'émissions DCS avec vérification renforcée Registre des crédits Procédure d'octroi de crédits	opérationnelle pour le calcul et la vérification des émissions. Émission de crédit et utilisation
La PAC et le commerce	Toutes les mesures visant à réduire les émissions	Les carburants à faible teneur en carbone et les carburants à émissions nulles sont encouragés lorsque des options moins coûteuses de réduction des émissions sont épuisées.	Le plafond prescrit le parcours souhaité et la politique, si elle est bien appliquée, garantit que le parcours est réalisé.	DCS avec vérification renforcée Procédure d'attribution du registre des quotas	Éventuellement compatible avec l'annexe MARPOL VI.Nécessite des modifications concernant: Calcul et vérification des émissions de l'ACV carburant Allocation et utilisation des quotas à des fins de conformité
Taxe sur les GES	Toutes les mesures visant à réduire les émissions	Les carburants à faible teneur en carbone et les carburants à émissions nulles sont encouragés lorsque la taxe est suffisamment élevée pour les rendre compétitifs par rapport aux combustibles fossiles.	Le parcours réel dépend de la réaction du secteur du transport maritime à l'incitation des gaz à effet de serre. fiscale	DCS avec renforcement possible de l'annexe VI de la convention MARPOL, ou nouvelle. Procédure de perception de l'annexe ou dela nouvelle convention fiscale. Procédure de versement des recettes	

Méthodes d'évaluation des incidences sur les États

La stratégie initialeprécise que les incidences des mesures sur les États doivent être évaluées avant l'adoption de la mesure et que les incidences négatives doivent être traitées de manière disproportionnée, le cas échéant. La stratégie mentionne spécifiquement les incidences suivantes:

- l'éloignement géographique et la connectivité des principaux marchés;
- la valeur et le type de cargaison;
- la dépendance vis-à-vis des transports;
- les frais de transport;
- la sécurité alimentaire;
- réaction aux catastrophes;
- rapport coût-efficacité; ainsi que
- progrès et développement socio-économiques.

Cette étude a entrepris d'élaborer des indicateurs pour chacune de ces catégories afin qu'ils puissent être utilisés dans les analyses d'impact. Ils sont présentés dans le tableau 2.

Tableau 2 — Résumé des indicateurs pour chaque catégorie à prendre en considération dans l'analyse d'impact

Incidence	Indicateurs
Éloignement géographique et la connectivité à l'axe	1. Part de marché des partenaires commerciaux x du pays, c'est-à-dire Commercialise la somme des volumes d'importation et d'exportation du pays de et vers leurs partenaires commerciaux. 2. Les frais de transport (chaque fois que des données sont disponibles) ou le temps de trajet entre le pays x et l'ensemble de ses marchés, combiné à la valeur du temps de la cargaison. Connectivité: Indice de connectivité maritime de la CNUCED (Liner Shipping Connectivity Index — Liner Shipping Connectivity Index — Liner Shipping Connectivity Index — Liner Shipping Connectivity Index — Liner Shipping Connectivity Index — Liner Shipping Connectivity Index, ajout à l'heure de transit et au numéro de transbordement pour cargaisons non conteneurisées.
Valeur de la cargaison et type fret et	1. La valeur du temps (TVP) des différents types de la durée de leur voyage. 2. Le taux ad valorem des différents types de fret.
Dépendance aux transports	1. Part des exportations et importations maritimes dans PIB du pays. 2. Les coûts et la disponibilité d'autres modes de transport de marchandises en provenance et à destination des États.
Frais de transport CAF/FAB;	1. Les frais de transport réels, par exemple les differences les frais de transport, tels que: a Une distance de transport maritime entre l'origine et la destination. b Coût des opérations logistiques telles que les coûts de manutention et de transbordement portuaires. c Coûts moyens d'exploitation des navires, qui sont explicitement ventilés par dépenses de capital et d'exploitation qui incluent les coûts du combustible maritime/soutage.

Incidence	Indicateurs
	d Les poids et valeurs des produits de base. e Temps de voyage entre l'origine et la destination, qui inclut le temps de transbordement et d'avitaillement des navires, et le temps de trajet dans l'arrière-pays. f Paires de pays d'origine et de destination. g Indicateurs socio-économiques tels que le PIB, le PIB par habitant des pays importateurs et exportateurs. h Qualité des infrastructures à l'origine et à destination. i Valeur du temps du produit de base JPY la valeur monétaire équivalente pour chaque unité passée par le produit au cours du transport entre l'origine et la destination.
Sécurité alimentaire	1. Part de la consommation alimentaire dans la moyenne dépenses des ménages des États. 2. La part des importations de denrées alimentaires dans la consommation totale de denrées alimentaires.
Réaction aux catastrophes	1. La part des produits importés qui est cruciale pour apporter une aide en cas de catastrophe et qui est soutenue par le transport maritime dans l'économie totale des États (PIB). 2. La part modale du mode maritime pour transporter des marchandises qui sont essentielles pour atténuer les conséquences d'une catastrophe, telles que les denrées alimentaires, les médicaments, les vêtements, les trousses de premiers secours, les tentes et l'alimentation électrique de secours. 3. Le coût total de la logistique pour répondre à la demande de biens et de services en cas de catastrophe.
Coût-efficacité	1. Le rapport entre l'évolution du PIB et le total des émissions de GES a diminué au niveau mondial. 2. Rapport entre l'évolution du volume des échanges de matières premières et le total des émissions de GES résultant des activités d'exportation et d'importation.
Progrès et développement socio-économiques	1. Produit intérieur brut (PIB). 2. Bien-être. 3. Emploi. 4. Niveau de pauvreté. 5. Les dépenses publiques consacrées aux services publics (par exemple, la santé, l'éducation, les transports). 6. Incidences sur le genre (niveaux de revenu des différents sexes).

Incidences des mesures

Cette étude établit que les modèles d'équilibre général informatique (EGC) peuvent fournir des informations utiles sur un certain nombre de types d'effets produits par les mesures de réduction des émissions de gaz à effet de serre.
Les estimations des incidences sont établies à partir d'un modèle EGC spécifique: GTAP, un modèle d'équilibre général multirégional, multisectoriel et calculable, caractérisé par une concurrence parfaite et des rendements à l'échelle constants, largement utilisé par la Commission européenne, le GIEC, l'OCDE, l'OMC et d'autres institutions. En raison des contraintes liées à la modélisation, les résultats sont établis pour un échantillon de différents pays, et l'accent est mis en particulier sur la fourniture de résultats aux économies des PEID et des PMA.

Le rapport a modélisé les incidences d'une situation dans laquelle 50% des carburants utilisés par le transport maritime sont des carburants à émissions nulles (carburants «power-to-x»).En raison de l'incertitude quant aux coûts de ces carburants, une estimation élevée et à faible coût a été modélisée.
Les résultats de la modélisation montrent l'incidence de la transition énergétique indépendamment de la mesure adoptée. Si des mesures visant à lever des recettes sont mises en œuvre et si une partie des recettes est utilisée en dehors du secteur du transport maritime, l'augmentation des coûts pour le secteur sera plus faible et les répercussions seront plus importantes.

Les résultats montrent que les effets générés par une politique généralisée de réduction des émissions de gaz àeffet de serre sont généralement bien inférieurs à un dixième de pourcentage pour la plupart des pays et régions, bien qu'ils varient d'un type d'économie à l'autre. Les effets sont faibles parce que les importations et les exportations représentent souvent une faible part du PIB et que les variations des valeurs des importations et des exportations sont souvent partiellement compensées par des changements dans la production intérieure, la consommation et les investissements. Les économies à revenu élevé affichent des résultats divers: certains ont des effets positifs nets et d'autres sont nets négatifs. Les économies à revenu moyen et les économies émergentes étudiées ont principalement eu des effets positifs nets. En revanche, les PEID et les PMA ont souvent eu des incidences négatives (dans 20 des 27 économies étudiées) et, dans des cas exceptionnels, l'incidence négative nette la plus importante (jusqu'à -3% du PIB).
Deplus amples informations sur la manière dont les différentes économies subissent les incidences sont présentées, notamment en utilisant les résultats ventilés par secteur du modèle GTAP pour deux économies émergentes, à savoir l'Inde et le Brésil. Ces résultats détaillés montrent que, si l'incidence globale sur une économie peut être faible (+ 0.01 — + 0,02% du PIB pour le Brésil, en fonction du prix du carbone, et + 0.001 à 0,002% pour l'Inde), la structure de l'économie évolue à mesure que certains secteurs se développent et que d'autres se contractent. Certains secteurs bénéficient de la substitution des importations, tandis que la compétitivité internationale d'autres secteurs évolue, parfois de manière positive, dans d'autres cas.

Les PEID du Pacifique ont généralement des données de modélisation de qualité médiocre, de sorte que les résultats de la modélisation sont moins précis. Les incidences potentielles sur ces États font l'objet de discussions plus approfondies sur le plan qualitatif. Un grand nombre des incidences de cette région devraient être révélatrices de celles que connaissent d'autres économies des PEID et sont liées à la forte dépendance à l'égard du transport maritime pour les nombreuses marchandises importées (y compris les produits énergétiques qui sont ensuite plus en cascade par l'augmentation des coûts du transport interrégional et national).Les PEID du Pacifique sont également fortement dépendants du transport maritime pour faire face aux catastrophes et ont une incidence sur leur capacité à réagir si la politique en matière de gaz à effet de serre dans le domaine du transport maritime international réduit les volumes et la fréquence du transport maritime. Cet impact ne s'accroît qu'à mesure que les effets du changement climatique sont de plus en plus ressentis.

Traiter de manière disproportionnée les incidences négatives

La stratégie initiale indique que les incidences négatives sur les États devraient être traitées de manière disproportionnée, le cas échéant.

Cette étude recense plusieurs façons de traiter de manière disproportionnée les incidences négatives, qui peuvent être regroupées en deux catégories:

- Exemptions ou différenciation (applicables à toutes les mesures).Elles pourraient être fondées sur l'itinéraire, par exemple pour faire face aux incidences sur des États spécifiques; à base de cargaisons, par exemple pour traiter des types d'impacts spécifiques, tels que les incidences sur la sécurité alimentaire et la réaction aux catastrophes; fondées sur des navires, par exemple pour traiter les incidences sur les États provenant d'une ancienne flotte ou d'une flotte avec petits navires; ou en fonction du temps, par exemple une introduction progressive pour permettre aux États de se préparer plus longtemps à une politique donnée.
- Utilisation des recettes (applicable uniquement aux mesures qui génèrent des recettes).Les politiques qui génèrent des recettes pourraient l'appliquer en matière de renforcement des capacités; investissements dans les services de transport maritime; investissements dans les infrastructures portuaires et hinterland; soutien financier inconditionnel; ou un soutien lié au climat.

L'utilisation des recettes présente, par rapport à la première catégorie, deux avantages qui découlent tous deux de l'hypothèse selon laquelle les politiques génératrices de recettes imposeraient les mêmes exigences à tous les navires. Si tel est le cas, il n'y a pas de risque de fuite de carbone dans le secteur du transport maritime, car il n'y aura aucun avantage à changer de routes, de cargaisons ou de navires afin d'éviter les coûts découlant de la politique. En outre, il n'y a pas de dilution de l'incitation à l'innovation qui se produirait si certains navires ou routes étaient exemptés.

Toutefois, il pourrait être difficile, sur le plan politique, d'augmenter les recettes et de décider de la manière dont elles devraient être utilisées.

Parmi les options possibles pour redistribuer les recettes accumulées grâce à une politique de réduction des émissions de gaz à effet de serre, nous considérons les investissements dans le fonds pour le climat et les infrastructures portuaires et de l'arrière-pays comme les mesures les plus prometteuses. Elles ont toutes deux un potentiel élevé en matière de prévention des fuites de carbone et d'annulation des incidences négatives sur les États. Par conséquent, pour tirer parti des points forts des deux mesures, les recettes générées par une mesure d'action peuvent être réinvesties en faveur du fonds pour le climat et, dans la mesure du possible, pour le développement ciblé des infrastructures portuaires et intérieures.

Il convient denoter que cette analyse ne tient pas compte de la facilité de parvenir à un accord entre les États, car il est impossible d'évaluer quand les États se sont abstenus d'exprimer leurs préférences pour l'une ou l'autre option lors du MEPC.Il convient également de noter que les avantages liés à l'utilisation des recettes diminueraient fortement s'ils étaient associés à des exonérations.

1 Introduction

1.1 Background

In spring 2018, MEPC 72 adopted the Initial Strategy on the Reduction of GHG Emissions from Ships (MEPC 72/17/Add.1, Annex 11). As part of the Initial Strategy, the following levels of ambition regarding the development of the carbon intensity and the GHG emissions of international shipping have been set:

- compared to 2008, the fleet's carbon intensity is to be reduced by at least 40% by 2030;
- GHG emissions from international shipping are to peak as soon as possible;
- compared to 2008, the fleet's total annual GHG emissions are to be reduced by at least 50% by 2050;
- efforts are to be pursued to reduce the fleet's carbon intensity towards 70% by 2050; and
- efforts are to be pursued towards phasing out the GHG emissions from international shipping as called for in the Vision as a point on a pathway of CO_2 emissions reduction consistent with the Paris Agreement temperature goals.

To accomplish these levels of ambition, short-, mid- and long-term policy measures have to be implemented as part of the Initial GHG Strategy.

Regarding the sector's emission reduction options, there is a range of efficiency improving options and renewable energy options readily available that can add to the sectors reduction of its GHG emissions. For the sector to decarbonize, however, it is understood that the sector has to apply zero fossil carbon fuels in the long run. These fuels are currently, if at all, only available on a small scale. The policy measures that have to implement the targets of the Initial Strategy should therefore incentivize the uptake and development of low/zero fossil carbon fuels. And since these fuels are expected to be relatively expensive, even if learning and scaling effects are considered, the fleet's energy efficiency improvement and uptake of other renewable energy options will nevertheless play a crucial role in the decarbonisation of the sector and should therefore also be incentivized by the policy measures established to implement the targets of the Initial GHG Strategy.

In a previous study performed by the consortium, potential short-term policy measures have been proposed and analysed[3], whereas the current study focusses on potential mid- and long-term measures.

In the Initial GHG Strategy a non-exclusive list of candidate mid-term and long-term policy measures is given (see Annex A) which will be considered in this analysis.

1.2 Objective and scope

Objective

This study aims at informing the forthcoming IMO discussions on mid- and long-term emission reduction measures and their impacts on States, based on a transparent methodology. This is done by identifying the advantages and disadvantages of measures.

The study has started out by developing a long list of all possible measures that are capable of ensuring that the shipping sector phases out its GHG emissions, as called for in the Initial Strategy. It then evaluates these measures on criteria of environmental

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3 CE Delft, UMAS, Lloyd's Register, Öko-Institut, 2019, Study on methods and considerations for the determination of greenhouse gas emission reduction targets for international shipping.

effectiveness (i.e. the incentive provided to a fuel transition), cost-effectiveness, and predictability. The best-scoring measures have been further developed.

Another objective of the study is to better understand the the possible impacts on States of a measure capable to decarbonise the sector based on a computable general equilibrium model supplemented with case studies.

This study analyses global measures which can be agreed and adopted by the IMO and follow from the Initial IMO Strategy on reduction of GHG emissions from international shipping. Regional measures and the possible interactions between regional measures and global measures are beyond the scope of this study.

Scope

Regarding the potential mid- and long-term policy measures, the analysis focusses on policy measures which are capable of ensuring a complete phase-out of GHG emissions in line with the Initial Strategy, provided that they are designed with sufficient stringency. We therefore exclude certain policy measures from the analysis and consider certain policy measures as supporting/complementary measures only:

- Policy measures aimed to reduce the energy consumption of ships rather than the CO_2 emissions or the fossil carbon content of the fuel are discarded from the analysis.
- Measures that incentivize an improvement of the ships' energy efficiency (as opposed to carbon efficiency) including measures that incentivize a reduction of the ships' speed are not discarded, but considered as potential supporting/complementing policy measure only.
- Policy measures that rely on offsets[4] are discarded from the analysis because the ambitions formulated in the Initial Strategy are related to the carbon intensity and the GHG emissions of international shipping which implies that in-sector reductions are required to meet these targets. Moreover, as countries are making their contributions to the Paris Agreement and global anthropogenic emissions are reduced, offsets will become scarcer.

We further assume that the *short*-term measure which has been agreed by MEPC will be implemented in 2023 and will improve the fleet's energy efficiency in line with the Initial GHG Strategy's 2030 carbon intensity ambition. For the study at hand this does not mean that we discard mid- and long-term measures that aim at improving the fleet's efficiency, it rather means that we do not assess candidate mid- and long-term policy measures regarding their impact on the fleet's efficiency.

Regarding the difference between mid- and long-term policy measures, we do not consider certain measure types to be more suitable as mid- or long-term measure. The main distinguishing factors between mid- and long-term measures are rather considered to be the implementation timelines of the measures[5], the stringency levels of the measures and a certain logic implementation sequence of the measures.

Regarding the type of emissions, the focus of the analysis lies on CO_2 emissions rather than on GHG emissions. This is considered a reasonable focus, because CO_2 emissions are the lion's share of the GHG emissions of international shipping — according to the IMO Third GHG Study around 98% in 2012.

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[4] Offsetting gives the possibility to reduce GHG emissions outside instead of inside the sector. This requires the out-of-sector emission reductions to be translated into purchasable emission reduction certificates also referred to as offsets.

[5] As specified in the Initial Strategy, possible mid-term measures could be measures finalized and agreed by the Committee between 2023 and 2030 and possible long-term measures could be measures finalized and agreed by the Committee beyond 2030.

1.3 Methodology

In order to develop a shortlist of candidate mid- and long-term policy measures:

1. We first identify all conceivable, roughly defined policy measures that fall within the scope of the study. A rough definition of a measure thereby includes the type of the measure (e.g. levy or emissions trading) as well as the measure base (e.g. CO_2 emissions or carbon intensity). And the list of all conceivable measures has been established by combining the different possible options for these two dimensions.
2. We then establish a longlist of potential main and potential supporting mid- and long-term measures (see Table 2 for the longlist of main mid- and long-term measures). We thereby consider the following measures as supporting measures rather than main measures: first, measures that, as stand-alone measures, do not allow the sector to fully decarbonize and second, measures that cannot be implemented as a standalone measure, but have to be combined with a revenue generating measure.
3. We finally carry out **multi-criteria assessments** to establish a shortlist of candidate mid- and long-term policy measures (see Chapter 3). To this end, assessment criteria are selected in the first instance. Then the long-listed main policy measures are scored per criterion relative to each other. And finally, multi-criteria assessments of the long-listed policy measures are carried out allowing for the possibility to apply a certain subset of criteria and to assign different weights to the different criteria considered.

Based on the multi-criteria assessments a short-list of measures to be further analysed is proposed.

In order to assess the impacts on States and identify ways to address disproportionally negative impacts literature review has been conducted.

Impacts on States have been assessed in two ways. First, a computable general equilibrium model has been applied to analyse the impacts of a generic measure to decarbonise shipping on GDP and trade for all countries. Second, three case studies have been conducted, two in order to provide more detail of how the impacts on States are built up, and one in order to analyse the impacts on States for which the model input data are possibly less accurate.

1.4 Outline of the report

Chapter 2 systematically identifies all possible measures capable of ensuring a transition of international shipping from the current reliance on fossil fuels to renewable and low-carbon fuels. Chapter 3 develops selection criteria and selects four measures, the design of which is further elaborated in Chapter 4.
Chapter 5 develops indicators for the assessment of impacts on States and evaluates how these indicators can be quantified. Chapter 6 analyses how disproportionally negative impacts on States can be addressed. Chapter 7 quantifies the impacts on States.

2 Identification of candidate measures

2.1 Introduction

This chapter systematically identifies all possible measures capable to decarbonise the sector and ensuring a transition of international shipping from the current reliance on fossil fuels to renewable and low-GHG fuels. Starting point of the identification of candidate mid- and long-term measures to reduce GHG emissions from international shipping is a list of all conceivable, roughly defined policy measures that fall within the scope of the study as specified under Section 1.2.

A rough definition of a measure thereby includes the type of the measure as well as the measure base.[6] And the list of all conceivable measures has been established by combining the different possible options for these two dimensions.

To give an example: 'Cap & trade emissions trading scheme' and 'Standard' are two types of measures and 'CO_2 emissions' and 'Operational CO_2 efficiency' are two measure bases. Combining these options gives us three potential candidate measures:

Measure base Type of measure	CO_2 emissions	Operational CO_2 efficiency
Cap & trade emissions trading scheme	Cap & trade emissions trading scheme based on the sector's annual CO_2 emissions	-
Standard	Ship CO_2 emission standard	Ship operational CO_2 efficiency standard

Note that at this stage, to keep the analysis manageable, we do not consider combinations of different policy measures and different uses of the revenue a measure might generate. When assessing the different policy measures we can however account for the fact that some measures do generate revenue whilst others do not.

2.2 Types of measures

We differentiate five main types of measures which will be explained in more detail hereafter:

1. Pricing mechanism.
2. Standard.
3. Funding.
4. Facilitating measures.
5. Obligation.

6 For a comprehensive overview of the relevant design options please go to Annex B.

1. A ***pricing mechanism*** is a measure that explicitly or implicitly puts a price on ships' emissions or on part of their emissions. Market based measures, including those that have been assessed by the MBM Expert Group (MEPC 61/INF.2) fall into this category, as well as possibly the first three mid-term measures mentioned in the Initial IMO Strategy (implementation programme for the effective uptake of alternative low- and zero-carbon fuels; operational energy efficiency measures for both new and existing ships; and new/innovative emission reduction mechanism(s), possibly including Market-based Measures (MBMs), to incentivize GHG emission reduction). Note that the long-term measures are so broadly described that it is hard to categorise them (pursue the development and provision of zero-carbon or fossil-free fuels to enable the shipping sector to assess and consider decarbonization in the second half of the century; and encourage and facilitate the general adoption of other possible new/innovative emission reduction mechanism(s)).

The following pricing mechanisms are potentially relevant types of measures in this context:

a Levy or tax.
b Subsidy.
c Emissions trading scheme (i.e. a sector standard combined with a pricing mechanism).

and ship specific standards combined with a pricing mechanism:

a Baseline & credit scheme.
b Ship specific standard combined with a penalty/with a penalty and a reward.

We briefly discuss each type of measure below:

a A CO_2 emissions tax/levy could be implemented to incentivize ships to reduce their CO_2 emissions. Depending on the design of the measure, the tax/levy could be raised by national governments to potentially be incorporated into the national budget[7] or by an international body to be established to feed into an international fund.[8]
b Some subsidies are also able to put a price on the emissions of ships. If ships' would for example receive a subsidy depending on their GHG emission reductions compared to a baseline, emitting a unit of CO_2 would be associated with opportunity costs, i.e. with forgone revenues.
c Under a cap-and-trade emissions trading scheme, ships would be obliged to annually submit allowances for each unit of CO_2 emitted, with a limited total amount of allowances becoming annually available for the sector, gradually declining over time. The allowances would be auctioned off and/or (partially) be allocated for free to the ships with the possibility to trade the allowances on a secondary market. Ships with low CO_2 emissions would have to buy less allowances or could sell some of their allowances to ships with relatively expensive CO_2 abatement options. The EU ETS is an example for a cap-and-trade system applying for power stations, industrial plants and airlines operating between EEA countries[9].
d Under a *baseline & credit scheme*, a standard would be set which the fleet or a segment thereof would have to meet on average: ships that perform better than the standard would be able to receive credits for their overachievement and ships that perform worse than the standard would be obliged to buy credits to compensate for their underachievement. The baseline can thereby

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7 Earmarking of the revenues (e.g. mandatory use of the revenues for the reduction of the climate impact of the maritime shipping sector) could be an option here too, at least if national laws allow for earmarking.
8 According to our understanding the term 'levy' is broader defined than the term 'tax': Whereas both a tax and a levy could be implemented by national states generating revenues for the benefit of national budgets, a tax cannot, per definition, be implemented to generate revenues for the benefit of an international fund. But please note that the terms levy and tax are often used interchangeably.
9 28 EU countries plus Iceland, Liechtenstein and Norway.

be set in absolute terms (e.g. CO_2 emissions) or relative terms (e.g. carbon intensity).
A baseline & credit scheme has for example been implemented in Alberta.[10] The California Low-Carbon Fuel Standard is another example for such a scheme.[11]

e A standard combined with a penalty would set a ship-specific standard with ships not meeting the standard having to pay a fee. The fee could be set to incentivize further reductions by relating the fee to the actual level of underachievement or it could be set as a fixed fee. The revenue could be recycled back to reward overachieving ships as an integral part of the measure (standard & fee & rebate also referred to as feebate in the literature). In contrast to a baseline & credit scheme, a feebate would not require credit trading, but a centralized administration collecting the penalties and disbursing the rewards.

2. A **standard** is an example for command-and-control regulation prescribing a specific level of performance (emission level, efficiency level, speed level, etc.) not to be exceeded. Some mid-term measures can fall into this category, depending on how they are designed. These are: implementation programme for the effective uptake of alternative low- and zero-carbon fuels (when designed as e.g. a low-carbon fuel standard); operational energy efficiency measures for both new and existing ships (when designed as an operational energy efficiency) standard; and new/innovative emission reduction mechanism(s) to incentivize GHG emission reduction (when designed as an emissions standard).

Under a standalone standard, no flexibility except maybe a flexibility over time[12] would be offered to ships. Ships not complying with a standalone standard would have to be detained until they can credibly prove that steps will be taken to ensure compliance within a certain period of time.

A standard & penalty scheme or a feebate scheme can be considered a standard (or a command-and-control measure) with flexibility.

3. ***Funding measures*** provide financial support to an activity that can directly or indirectly contribute to a reduction of GHG emissions of international shipping. Some mid-term measures can fall into this category, depending on how they are designed. An 'implementation programme for the effective uptake of alternative low- and zero-carbon fuels' can consist of or include funding, as do 'new/innovative emission reduction mechanism(s)'.

Next to subsidies which can be considered a pricing mechanism (see above), there are other types of funding measures conceivable that can directly or indirectly contribute to the decarbonisation of the shipping sector. Subsidies for R&D projects or grants for the adoption of technical emission reduction measures are examples for such funding measures. A levy could be implemented with the sole aim of feeding an international fund that would provide the means for such a funding measure.

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10 The Carbon Competitiveness Incentive Regulation (CCIR) applies to any facility that emits 0.1 Mt or more of carbon dioxide equivalents per year. Facilities exceeding their sector-based product benchmark(s) can comply with CCIR using credits generated at other facilities or Alberta-based offset projects (World Bank Group, 2018).

11 https://ww3.arb.ca.gov/fuels/lcfs/lcfs.htm

12 Ships might be allowed to comply with a standard within a certain period of time.

4. ***Facilitating measures*** are measures that can facilitate the ships' reduction of GHG emissions by different means like for example enhancing ship owners' knowledge on the GHG reduction options for his fleet, by providing an information platform for ship owners to exchange experiences regarding GHG reduction options. The Ship Energy Efficiency Management Plan as implemented by the IMO is an example for such a facilitating measure. Two of the mid-term measures listed in the Initial Strategy fall into this category: 'further continue and enhance technical cooperation and capacity-building activities such as under the ITCP'; and 'development of a feedback mechanism to enable lessons learned on implementation of measures to be collated and shared through a possible information exchange on best practice'.

Different measures that can facilitate the CO^2 emission reduction of ships are conceivable, like for example technical cooperation and capacity-building activities or the facilitation of information exchange on best practices.

5. And last but not least, ships could also become obliged to invest into/adopt certain GHG reduction options. Although such measures would not align well with the preference that the IMO generally exhibits for goal-based measures, some of the measures mentioned in the Initial Strategy could be designed to fall into this category. For example, an 'implementation programme for the effective uptake of alternative low- and zero-carbon fuels' could comprise an obligation for new ships to be built for specific, zero-carbon fuels.

In contrast to a standard, ships would under an ***obligation*** not have to meet a specific quantitative environmental target. To give an example, ships could become obliged to annually maintain their hulls or engines or to invest a certain amount to improve their efficiency.[13]

2.3 Measure base

We consider the base of a measure as being the parameter the measure aims to reduce/improve in the first instance. CO_2 emissions would for example be considered the measure base of a CO_2 emission tax.

To establish the different relevant measure bases for the candidate mid- and long-term measures, the main determinants of ships' CO_2 emissions have to be identified. Figure 1 gives a systematic overview of these determinants. For a better understanding, the boxes in the figure are numbered and these numbers are referred to in the following explanatory paragraph.

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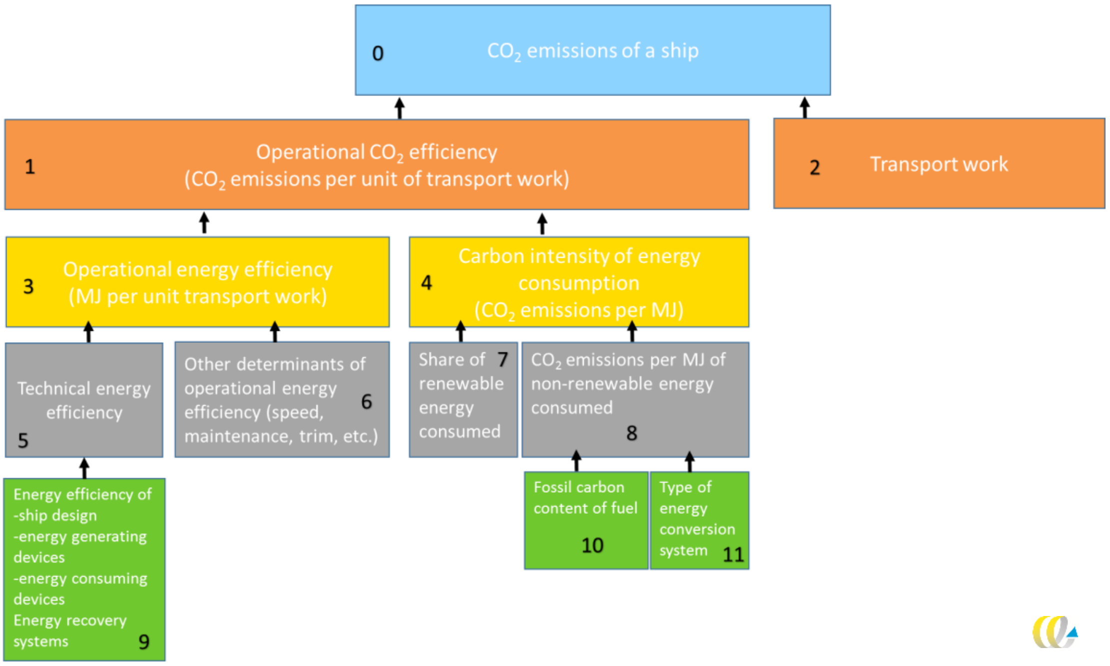
13 An investment obligation could either be designed as a levy with a central organisation collecting the investment capital in the first instance or it could be designed without a central collection point.

Figure 1 - Systematic overview of the determinants of a ship's CO_2 emissions



A ship's CO_2 emissions depend in the first instance on the ship's operational CO_2 efficiency (1) and its transport work (2). The former (1) is determined by two factors: first, the operational *energy* efficiency of the ship (3) and the carbon intensity of a ship's energy consumption or fuel (4).

The ship's operational energy efficiency (3) depends on the ship's technical energy efficiency[14] (5) and other factors (6) like the ship's speed, its maintenance, etc. The technical energy efficiency of a ship (5) is finally determined by (9) the energy efficiency of the ship design (e.g. hull design), of the energy generating devices (e.g. engine), and of the energy consuming devices (e.g. propeller or air conditioning) on board a ship as well as on the energy recovery systems applied on board ships (e.g. waste heat recovery systems).

The carbon intensity of a ship's energy consumption or fuel (4) depends on the share of renewable energy the ship consumes, stemming e.g. from wind propulsion systems (7) and the CO_2 the ship emits per unit of non-renewable energy it consumes (8). The latter (8) is determined by the fossil carbon content of the fuel used (10) and the type of energy conversion systems used on board (11), like a combustion engine or a fuel cell in combination with an electric engine.

For the development of the longlist of candidate measures the following four categories of measure bases have been used:

1. CO_2 emissions (see determinant 0 in Figure 1).
2. Operational CO_2 efficiency (see determinant 1 in Figure 1).
3. Technical CO_2 efficiency (combination of determinants 5 and 4 in Figure 1).
4. Carbon intensity of energy consumption or fuel (see determinant 4 in Figure 1).

These measure bases have been selected with the aim to keep the level of aggregation of the determinants as high as possible, but at the same time allowing for measure bases other than CO_2 emissions as such.

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[14] Technical energy efficiency of a ship is actually the operational energy efficiency of the ship under standardized non-technical determinants.

Please note that we consider transport work (determinant 2 in Figure 1) as a measure base beyond the area of influence of the IMO; ships could of course nevertheless choose to reduce their annual transport work to comply with a policy measure that regulates the CO_2 emissions of a ship.

2.4 Longlist of candidate measures

In order to develop a meaningful longlist of candidate mid- and long term measures, we started off with an overview of all conceivable measures (see Table 17 in Annex C) by combining the different types of measures as specified under Section 2.2 with the different measure bases as specified under Section 2.3. Subsequently, measures were excluded by applying different criteria as will be explained in the following.

To come to a longlist of measures, we differentiated between, on the one hand, potential *main* policy measures and, on the other hand, potential *supporting* policy measures. Supporting policy measures could be implemented next to main policy measures or could compliment them directly.

We considered the following measures as supporting measures rather than main measures:

a Measures that, as stand-alone measures, do not allow the sector to fully decarbonize:
   1. Measures related to the ships' speed.
   2. Measures aimed at improving the *energy* efficiency rather than the CO_2 efficiency of ships.
   3. Facilitating measures and obligations.

b Measures that cannot be implemented as a standalone measure, but have to be combined with a revenue generating measure (subsidy and funding).

Pricing mechanisms other than subsidies that could only have a supporting function due to their measure base (e.g. a baseline & credit scheme based on ships' speed), were discarded even as supporting measures, because it is potentially very complex to combine a supporting pricing mechanism with a main pricing mechanism.

And finally, standalone standards have also been discarded since they are considered too rigid to be applied to existing ships.

Table 3 gives the resulting longlist of potential *main* mid- and long-term measures and Table 18 in Annex C the resulting longlist of potential *supporting* mid- and long-term measures.

Table 3 – Longlist of seventeen potential main mid- and long-term measures

Measure base Type of measure		CO_2 emissions	Carbon intensity
Pricing mechanism	**1**	Cap & trade emissions trading scheme targeting sectors' CO_2 emissions: • free allocation of allowances • auctioning of allowances • auctioning of allowances with centralized collection of revenues	
	2	Levy/tax targeting ships' CO_2 emissions: • with centralized collection of revenues • decentralized collection of revenues only	
Regulatory standard	**3**	Baseline & credit scheme targeting ships' annual CO_2 emissions	Baseline & credit scheme targeting: • ships' operational CO_2 efficiency • ships' technical CO_2 efficiency • ships' carbon intensity of energy consumption or fuel
	4	Standard & penalty scheme targeting ships' CO_2 emissions	Standard & penalty scheme targeting: • ships' operational CO_2 efficiency • ships' technical CO_2 efficiency • ships' carbon intensity of energy consumption or fuel
	5	Feebate scheme targeting ships' CO_2 emissions	Feebate scheme targeting: • ships' operational CO_2 efficiency • ships' technical CO_2 efficiency • ships' carbon intensity of energy consumption or fuel

Note that the last two measures are similar and could be considered to be variants of one another.

Note that the last two measures are similar and could be considered to be variants of one another.

The longlist of potential main mid- and long-term measures comprises seventeen pricing mechanisms:

- three alternative cap & trade emissions trading schemes (ETS);
- two alternative tax/levy schemes;
- four alternative baseline & credit schemes;
- four alternative standard & penalty; and
- four alternative feebate schemes[15].

To our knowledge nine of these thirteen measures have already been proposed to/discussed at the IMO.

These are:

1. A cap & trade ETS based on the sector's annual GHG emissions(e.g. MEPC 60/4/22) considering free allocation and/or auctioning of emission allowances.
2. A levy/tax based on ships' GHG emissions (e.g. MEPC 60/4/8 and MEPC 60/4/40) considering centralized or decentralized collection of revenues.
3. A baseline & credit scheme based on ships' technical GHG efficiency (e.g. MEPC 60/4/12).
4. A ship operational GHG efficiency standard (e.g. MEPC 67/5/4).
5. A baseline & credit scheme based on ships' operational GHG efficiency (e.g. MEPC 64/5/6).
6. A ship technical energy/GHG efficiency standard combined with a penalty (e.g. MEPC 60/4/39).
7. A ship GHG emission standard (e.g. MEPC 63/5/1).

In Annex D, an overview of GHG measure-related submissions to the IMO are given, categorized by measure type.

15 A ship standard combined with a penalty & reward is in the following referred to as feebate scheme.

3 Selection of measures

3.1 Assessment criteria for the selection of candidate measures

To establish a shortlist of candidate measures, assessment criteria have been selected. The most important criterion is that the selected measures are able to result in the decarbonisation of maritime transport. Since other measures are outside of the scope of the study, all measures fulfil this criterion.

In order de define other criteria, an overview of assessment criteria that have been applied/proposed at MEPC and a categorisation of these criteria have been developed (see Table 3).

The following assessment criteria have thereby been considered:

- the assessment criteria as applied by the IMO MBM Expert Group in the 2010 impact assessment (MEPC 61/INF.2);
- the assessment criteria as specified in the Draft Terms of Reference for further impact assessment of the proposed Market-based Measures for international shipping (MEPC 64/5) from March 2012; and
- the assessment criteria as specified in the Initial GHG Strategy (MEPC 72/17/Add.1, Annex 11).

Assessment criteria proposed in submissions of individual/subgroups of IMO members have thereby not been accounted for.

As Table 4 shows, we have differentiated the following eight different categories of assessment criteria:

1. Legal aspects.
2. Practical feasibility.
3. Impacts on administrations.
4. Direct impacts from the social perspective.
5. Impacts on maritime sector.
6. Indirect impacts as a consequence of the direct impacts on the maritime sector.
7. Aspects that should be considered when determining the indirect impacts.
8. Criteria to put the potential impacts into perspective.

To establish the shortlist of mid- and long-term measures, we focus at that stage of the project on the impacts on administrations (category 3), direct impacts from the social perspective (category 4) and the impacts on the maritime sector (category 5).

The indirect impacts as a consequence of the direct impacts on the maritime sector (category 6) as well as the aspects that should be considered when determining the indirect impacts (category 7) will be the focus of the quantitative assessment of the shortlisted measures.

Legal aspects and the practical feasibility (category 1 and 2) will be relevant for the further development of the shortlisted measures.

Table 4 - Overview and categorization of assessment criteria applied/proposed by MEPC

Categories of assessment criteria	Assessment criteria
Legal aspects	Relation to the principles and provisions of UNFCCC (and its Kyoto Protocol)
	Compatibility with WTO Rules
	Compatibility with customary international law, as depicted in the UNCLOS
	Legal aspects for National Administrations regarding implementation and enforcement
	Compatibility with existing enforcement and control provisions under IMO legal framework
Practical feasibility	Practical feasibility of implementation
Impacts on administrations	Additional administrative burden for National Administrations by implementing and enforcing measure
Direct impacts from the social perspective	Environmental effectiveness
	Socio-economic cost-effectiveness
Impacts on maritime sector	Cost-effectiveness
	Additional workload for individual ships, shipping industry and maritime sector as a whole
	Additional economic burden for individual ships, shipping industry and maritime sector as a whole
	Additional operational impact for individual ships, shipping industry and maritime sector as a whole
	Accommodation of current emission reduction and energy efficiency technologies
	Additional financial, workload and technical burden for shipbuilding industry and maritime sector in developing countries of implementing and enforcing the measure
	Impacts on shipping industries, in particular in developing countries
	Impact on transport costs
	Potential to provide incentives to technological change and innovation
	Impacts on marine fuels and alternative fuels
Indirect impacts as a consequence of direct impacts on the maritime sector	Impacts on trade and sustainable development
	Impacts on trade (including trade between developing countries), consumers and industries
	Impacts on consumers, especially in developing countries
	Impacts on prices of raw materials and commodities
	Impacts on energy and fuel prices
	Impacts on food prices, including food imports by developing countries, in particular LDCs, SIDS and remotely located developing countries with large trading distances;
	Impacts on food security
	Effects on the competitiveness and distortions in trade (with focus on developing countries, particularly on LDCs and SIDS and remotely located developing countries with long trading distances)
	Need for technology transfer to, and capacity building within developing countries (in particular LDCs and SIDs) in relation to implementation and enforcement of measure (including potential to mobilize climate change finance for mitigation and adaptation actions)
	Impacts on disaster response
	Impacts on socio-economic progress and development

Categories of assessment criteria	Assessment criteria
Aspects that should be considered when determining the indirect impacts	Geographic remoteness of and connectivity to main markets
	Cargo value and type
	Transport dependency
Criteria to put the potential impacts into perspective	Environmental cost-effectiveness in relation to the mitigation potential of other sectors
	Relative impact of measure compared with other expected cost increase impacts over the same time period

Sources: MEPC 61/INF.2; MEPC 64/5; MEPC 72/17/Add.1, Annex 11.

Table 5 gives an overview of the assessment criteria we have selected to establish a shortlist of mid- and long-term measures. We thereby differentiate the social/administrations and the sector perspective. For some criteria indicators have been developed as specified in the third row of Table 5.

Table 5 – Assessment criteria and according indicators selected to establish shortlist of mid- and long-term measures

	Assessment criterion	Indicators
Social/ administrations perspective	Compliance costs	• Cost-effectiveness of measure type • Range of reduction options directly incentivized • Incentive for the uptake of low/zero-carbon fuels at a relative early stage
	Administrative costs of sector and administrations	Expected costs for administrations and sector in implementation and operational phase of the measures
	Certainty with which emissions pathway can be followed	[criterion as such; no indicator required]
	Potential implementation hurdles	[criterion as such; no indicator required]
Sector perspective	Compliance costs	• Cost-effectiveness of measure type • Range of reduction options directly incentivized • Incentive for the uptake of low/zero-carbon fossil fuels at a relative early stage • Costs for remaining emissions
	Administrative costs of sector	Expected costs for the sector in the operational phase of the measure
	Certainty of compliance costs	[criterion as such; no indicator required]
	Other aspects of political feasibility	Potential major objections of sector not directly related to costs

For both perspectives it holds that the minimisation of compliance costs is desirable, whereas the costs to be minimized differ depending on the perspective.

For both perspectives, we have selected three indicators to approximate the compliance costs for the sector which are:

- the cost effectiveness of the measures type;
- the range of reduction options directly incentivized by the measure;
- the incentive for the uptake of low/zero-carbon fuels at a relative early stage.

A cost effective measure is a measure that allows, from the perspective of the total fleet, to achieve an emission target by means of the cheapest set of emission reduction measures available. In order to assess this criterion, we take both a static and a dynamic perspective. The static perspective, with current technology, is that a measure is cheapest when it directly incentivizes the broadest possible range of reduction options. The dynamic perspective, with technological development, is that a measure is cheapest when it incentivizes the uptake of low/zero-carbon fuels at a relative early stage, so that the demand-pull can be expected to trigger innovation which will lower the costs over time.

Note that the costs of tax payment or acquisition of emission allowances are only relevant from the sector perspective; from the social perspective these payments are considered to be a transfer from one party to another only.

Note also that only those measures that are associated with costs for (parts of) the remaining emissions, have the potential to generate revenues. The potential of a measure to generate revenues is probably considered a positive aspect by potential net recipients and probably considered a negative aspect by potential net contributing parties. For this reason the revenue generating potential of a measure is not used as an assessment criterion. When establishing a short-list of mid- and long-term measures, a differentiation between measures that do/do not generate revenue can of course be made.

Next to the compliance costs, the administrative costs have been selected as assessment criterion, with the administrative costs for the administration(s) not being relevant from the sector perspective.

Note that the environmental effectiveness of measures is in general a very important assessment criterion when comparing environmental measures from a social perspective. However, all measures considered here would be applied to decarbonise the sector which makes the environmental effectiveness a matter of stringency of the measure, at least if the scope of the measure covers the entire fleet. The costs against which the sector can decarbonise is then the measures' major distinguishing factor. A measure's potential for evasion also has an impact on the measure's environmental effectiveness. However, by selecting the ship as responsible entity for compliance, the evasion risk can be reduced significantly for all measures. In the further design of the measure it should however be borne in mind that each exemption (e.g. in terms of ship sizes) bears the risk of evasion.

And last but not least, we consider for both perspectives major aspects that may complicate the implementation of a measure. From the social/administrations perspective for example measures might be more difficult to implement that require an international centralized body to collect revenues and from the sector perspective, measures with 'operational efficiency' as a measure base and measures the design of which relies on ships' operational efficiency have the potential to be objected.

3.2 Development of a shortlist of candidate long-term measures

In order to establish a shortlist of candidate long-term measures we have assessed the longlisted policy measures in a two tiered approach. In a first step, the measures are ranked per criterion and in a second step, the measures are assessed by means of multiple criteria.

3.2.1 Ranking per criterion

In order to establish a shortlist of candidate long-term measures, the seventeen longlisted potential main mid- and long-term measures are assessed by means of the assessment criteria as presented in Section 3.1.

In the first instance the measures are assessed per criterion scoring the measures relative to each other, using five score levels (++/+/0/-/--). Table 5 shows the longlisted potential mid- and long-term measures and how we scored them per assessment criterion. Table 7 indicates the criteria that are relevant for each of the two perspective, i.e. the social/administrations and the sector perspective. And Annex E provides a detailed explanations of how the scores as presented in Table 6 have been established.

Table 6 – Assessment of longlisted long-term measures by means of the selection criteria

			Cost-effectiveness of measure type	Range of reduction options directly incentivized	Incentive uptake of low/zero fossil carbon fuels at relative early stage	Certainty with which emissions pathway can be followed	Costs for remaining emissions	Certainty of compliance costs	Administrative costs of sector & administration	Administrative costs of sector	Potential implementation hurdles (social/ admin. perspective)	Potential major objective (sector perspective)
	Measure type	Targeting…	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
1a	Cap & trade ETS (free allowances)		++	++	--	++	++	--	--	-	0	--
1b	Cap & trade ETS (auctioning of allow.+ centralized revenue collection)	…fleet CO_2 emissions	++	++	--	++	--	--	--	--	--	0
1c	Cap & trade ETS (auctioning of allowances)		++	++	--	++	--	--	-	--	0	0
2a	Levy/tax (+ centralized revenue collection)		++	++	--	0	--	++	+	++	--	0
2b	Levy/tax (no centralized revenue collection)	…ships' CO_2 emissions	++	++	--	0	--	++	++	++	0	0
3a	Baseline & credit scheme		++	++	--	++	++	--	+	0	0	0
4a	Standard & penalty scheme		--	++	--	-	++	++	+	++	0	--
5a	Feebate scheme		0	++	--	0	++	+	0	++	--	0
3b	Baseline & credit scheme		++	+	-	+	++	--	+	0	0	0
4b	Standard & penalty scheme	…ships' operational CO_2 efficiency	--	+	-	--	++	++	+	++	0	--
5b	Feebate scheme		0	+	-	-	++	+	0	++	--	--
3c	Baseline & credit scheme		++	0	0	+	++	--	+	0	0	--
4c	Standard & penalty scheme	…ships' technical CO_2 efficiency	--	0	0	--	++	++	+	++	0	0
5c	Feebate scheme		0	0	0	-	++	+	0	++	--	0
3d	Baseline & credit scheme	…ships' carbon	++	-	++	+	++	--	+	0	0	0
4d	Standard & penalty scheme	intensity of energy	--	-	++	--	++	++	+	++	0	0
5d	Feebate scheme	consumption or fuel	0	-	++	-	++	+	0	++	--	0

Table 7 - Criteria deemed relevant depending on the perspective

		Social/administrations perspective	Sector perspective
C1	Cost-effectiveness of measure type	X	X
C2	Range of reduction options directly incentivized	X	X
C3	Incentive uptake of low/zero fossil carbon fuels at relative early stage	X	X
C4	Certainty with which emissions pathway can be followed	X	
C5	Costs for remaining emissions		
C6	Certainty of compliance costs		X
C7	Administrative costs of sector & administrations	X	
C8	Administrative costs of sector	X	X
C9	Potential implementation hurdles (social/administrations perspective)	X	
C10	Potential major objective (sector perspective)		X

Based on this first assessment step, the conclusions can be drawn that:
there is not a single measure that scores worst or scores best on all criteria :

1. Policy measures that incentivize a broad range of mitigation options and will therefore be associated with relative low abatement/reduction costs, incentivize the uptake of low/zero fossil carbon fuel at a relative late stage, precisely because ships can choose out of a wide range of abatement options.
2. With the exception of a cap & trade emissions trading scheme, policy measures that generate revenue are associated with a certain degree of uncertainty when it comes to meeting a specific emissions pathway.

3.2.2 Multi-criteria assessment

In a second step, the policy measures have also been assessed by means of several criteria. To this end, the five score levels (++/+/0/-/--) have been converted into numerical values (2/1/0/-1/-2) and summed-up for the criteria considered in the mulita-criteria assessment. The criteria can thereby be assigned different weights. Note thereby that since the scale of the scores can differ between the criteria, the outcome of this multi-criteria assessment has to be interpreted carefully to come to valid conclusions.

Whilst it is clear that for a public regulator, the social perspective is more relevant, it is also relevant politically to understand how the sector is affected and where the social and sectoral perspective diverge. For this reason, the multi-criteria assessment is done for both perspectives. In the selection of the measures, the results of the sectoral assessment will dominate.

Table 8 and Table 9 present the outcomes of the two multi-criteria assessments we conduct on for each perspective, i.e. the social/administrations perspective and the sector perspective . In the assessments two criteria which we deemed most relevant per perspective are given more weight than the other criteria: from the social/administrations perspective the certainty with which an emissions pathway can be followed as well as potential implementation hurdles and from the sector perspective the certainty of the compliance costs as well as potential major objectives.

Note that in some cases, different measures have the same scores; these measures are listed in random order and given the same ranking number in column two and four of the tables.

Table 8 – Setting and outcome of the multi-criteria assessment from the social/administrations perspective

	Multi-criteria assessment 1		
Settings of multi-criteria assessment	All criteria deemed relevant from the social/administrations perspective (see Table 7) have been considered		
	Two criteria (C4: Certainty with which emissions pathway can be followed, C9: Potential implementation hurdles) has been given more weight (3x)		
Ranking of measures as outcome of the according multi-criteria assessment	1	3a.	Baseline & credit scheme targeting ships' CO_2 emissions
	2	1c.	Cap & trade ETS (auctioning of allowances)*
		3d.	Baseline & credit scheme targeting ships' carbon intensity of energy consumption or fuel
	3	1a.	Cap & trade ETS (free allowances)
		3a.	Baseline & credit scheme targeting ships' operational CO_2 efficiency
		3c.	Baseline & credit scheme targeting ships' technical CO_2 efficiency
	4	2b.	Levy/tax (no centralized revenue collection)*
	5	1b.	Cap & trade ETS (auctioning of allowances + centralized revenue collection)*
		5d.	Feebate scheme targeting ships' carbon intensity of energy consumption or fuel
	6	2a.	Levy/tax (+ centralized revenue collection)*
	7	4a.	Standard & penalty scheme targeting ships' CO_2 emissions*
	8	5a.	Feebate scheme targeting ships' CO_2 emissions
		4d.	Standard & penalty scheme targeting ships' carbon intensity of energy consumption or fuel*
	9	4b.	Standard & penalty scheme targeting ships' operational CO_2 efficiency*
		4c.	Standard & penalty scheme targeting ships' technical CO_2 efficiency*
	10	5b.	Feebate scheme targeting ships' operational CO_2 efficiency
		5c.	Feebate scheme targeting ships' technical CO_2 efficiency

Note: * indicates that a measure generates revenues.

Table 9 – Setting and outcome of the multi-criteria assessment from the sector perspective

	Multi-criteria assessment 2		
Settings of multi-criteria assessment	All criteria deemed relevant from the sector perspective (see Table 7) have been considered		
	Two criteria (C6: Certainty of compliance costs, C10: Potential major objections) has been given more weight (3x)		
Ranking of measures as outcome of the according multi-criteria assessment	1	4d.	Standard & penalty scheme targeting ships' carbon intensity of energy consumption or fuel
	2	2a.	Levy/tax (+ centralized revenue collection)*
		2b.	Levy/tax (no centralized revenue collection)*
		4a.	Standard & penalty scheme targeting ships' CO_2 emissions
		4c.	Standard & penalty scheme targeting ships' technical CO_2 efficiency
	3	5a.	Feebate scheme targeting ships' CO_2 emissions
		5c.	Feebate scheme targeting ships' technical CO_2 efficiency
	4	4b.	Standard & penalty scheme targeting ships' operational CO_2 efficiency
	5	5b.	Feebate scheme targeting ships' operational CO_2 efficiency
	6	5d.	Feebate scheme targeting ships' carbon intensity of energy consumption or fuel
	7	3d.	Baseline & credit scheme targeting ships' carbon intensity of energy consumption or fuel
	8	3c.	Baseline & credit scheme targeting ships' technical CO_2 efficiency
	9	1b.	Cap & trade ETS (auctioning of allowances + centralized revenue collection)*
		1c.	Cap & trade ETS (auctioning of allowances)*
		3a.	Baseline & credit scheme targeting ships' CO_2 emissions
		3b.	Baseline & credit scheme targeting ships' operational CO_2 efficiency
	10	1a.	Cap & trade ETS (free allowances)

Note: Measures which generate revenue regardless of how they are designed are denoted with an asterisk. Other measures can be designed to raise revenues.

As Table 6 shows, measures that are cost-effective, are associated with a relative high certainty with which an emissions path can be followed and which not require the establishment of an international administration to centrally collect revenues score highest:

1. Baseline & credit scheme targeting ships' CO_2 emissions.
2. Cap & trade ETS (auctioning of allowances).
3. Baseline & credit scheme targeting ships' carbon intensity of energy consumption or fuel.
4. Cap & trade ETS (free allowances).
5. Baseline & credit scheme targeting ships' operational CO_2 efficiency.
6. Baseline & credit scheme targeting ships' technical CO_2 efficiency.

Note that from these measures only a cap & trade ETS could generate revenues that could potentially be used for compensating purposes.

As Table 9 shows, measures that are associated with a relative high certainty of the compliance costs, with relative low administrative costs as well as measures that neither rely for their design on ships' operational efficiency nor have operational efficiency as measure base score highest:

1. Standard & penalty scheme targeting ships' carbon intensity of energy consumption or fuel.
2. Levy/tax.
3. Standard & penalty scheme targeting ships' CO_2 emissions.
4. Standard & penalty scheme targeting ships' technical CO_2 efficiency.
5. Feebate scheme targeting ships' CO_2 emissions.
6. Feebate scheme targeting ships' technical CO_2 efficiency.

From these measures only the standard & penalty schemes and the levy/tax generate revenues that could potentially be used for compensating purposes.

Based on the sectoral multi-criteria assessments the four best scoring measures plus two that score well in a sectoral perspective are:

1. Baseline & credit scheme targeting ships' CO_2 emissions.
2. Cap & trade ETS (auctioning of allowances).
3. Baseline & credit scheme targeting ships' carbon intensity of energy consumption or fuel.
4. Baseline & credit scheme targeting ships' operational CO_2 efficiency.
5. Standard & penalty scheme targeting ships' carbon intensity of energy consumption or fuel.
6. Levy/tax.

Because the design of a baseline and credit scheme targeting ships' CO_2 emissions is very similar to the design of an emissions trading scheme, the next chapter discusses the design of these measures together.

4 Design of selected measures

4.1 Low-GHG fuel standard

The low-GHG fuel standard sets a standard for the lifecycle GHG emissions per unit of energy of a fuel. Ships would need to use fuel which has GHG emissions equal to or lower than the standard. If the standard is reduced to zero over time, ships will be required to use renewable and zero-carbon fuels.

There are at least three ways in which the requirement on ships can be designed:

First, each ship can be required to comply continuously with the standard. This means that it needs to use compliant fuels exclusively. When the standard has not yet reached zero, these fuels can be blends of fossil fuels or zero-carbon fuels. Because the latter are projected to be much more expensive than fossil fuels, blends will be the most cost-effective option for the transition period. This also means that this design will incentivise so-called drop-in fuels (fuels that can be used in existing ships without modifications and that can be blended with fossil fuels) over fuels that require different technology.

Second, each ship can be required to comply with the standard on average within a certain compliance period. This means that it can either use compliant fuels continuously or alternate between renewable and fossil fuels. It may also use renewable fuels for e.g. auxiliary engines and boilers and fossil fuels for the main engine, as long doing so ensures that it meets the standard. Like the continuous compliance, time-averaged compliance would also favour drop-in fuels because there will be no incentive to overcomply, although it would be possible .

Third, ships can be required to comply with the standard on average within a group of ships. This means that, in addition to the two compliance options mentioned above, a group of ships can comply when some of them sail on overperforming fuels (e.g. zero-emission fuels like ammonia or methanol produced exclusively with renewable energy) and some of them sail on fuels that do not meet the standard (e.g. fossil fuels), as long as the average GHG emissions per unit of fuel of the group meets the standard. The advantage of pooled compliance is that it incentivises the use of zero-GHG fuels from the start of the measure and thus supports innovations both for drop-in fuels and for new fuel types. The disadvantage is that the governance is more intricate. One way to ensure that pooled compliance can be properly enforced is to establish a baseline-and-credit trading scheme in which ships that opt for pooled compliance can participate. (Note that ships can always choose to comply by using fuels that meet the standard, so there is no requirement to participate in the baseline-and-credit trading scheme).

The baseline-and-credit trading scheme would allow ships that have used fuels with higher emission intensities than the standard to make up for the difference with credits. These credits are generated by ships that have sailed on fuels with lower emission intensities than the standard and which can apply to the regulator for standards. When the demand for credits is higher than the supply, the price of credits will increase thus incentivising ships to generate credits.

A baseline-and-credit trading scheme requires a registry of credits in order to ensure that it is always clear who owns a credit and that credits can be used only once for compliance. The registry indicates how many credits each ship has. Credits should be transferable so that non-compliant ships can buy them from overperforming ships. In a global system, the registry should be global. Ships can register with their IMO number. Credits can be granted by flag states based on fuel and emissions data submitted to them as part of the Data Collection System. When a ship submits data showing that is has overshot the standard, it needs to present sufficient credits to its Flag State. These credits will then be cancelled so that they cannot be used again for compliance.

The standard could start a notch below the average GHG intensity of the fuel at the time of implementation and be reduced to zero in a pace consistent with the Paris Agreement temperature goals as referred to in the IMO Strategy.

The lifecycle GHG emissions are the sum of emissions during the production and transport of the fuel and emissions during combustion. The production and transport emissions would be indicated on the bunker delivery note or a similar document and be handed over to the ship. The bunker delivery note would then indicate the carbon intensity of the fuel at its point of delivery to the ship, including GHGs emitted during production, transport, storage, refining, et cetera. The BDN should specify whether default values have been used (such as for example in the RED II or the California LCFS) or whether tailored calculations have been made. In the latter case, the calculations should be certified. The emissions on the ship depend on the energy conversion process. This can be based on type approval data of engines or fuel cells.

Note that the standard only refers to fuel. This means that it is not necessary to distinguish between ship types (there is no need for ship-specific reference lines) and that all ships can participate in the system.

MARPOL Annex VI appears to be a suitable legal instrument for this measure. Currently, MARPOL Annex VI regulates the sulphur content of fuels in Regulation 14 and it is conceivable to add a regulation which regulates the GHG intensity of the fuel. Regulation 4 (on equivalent measures) could be amended in order to allow for compliance with credits. MARPOL Annex VI should also regulate how the GHG intensity of the fuel is to be determined.

In its basic form, the low-GHG fuel standard would not raise revenues. If it were desirable to raise revenues with this measure, e.g. in order to address disproportionally negative impacts, it would be conceivable to organise a sale or auction of credits. Since these auctioned credits would not be issued on the basis of overcompliance, they would not represent emission reductions. In order to ensure the same outcome in terms of emission reductions, the standard could be tightened. To give an example: the same environmental result would be achieved if the standard would be set at 100 as when the standard would be set at 90 while auctioning credits of ten multiplied by the projected amount of fuel used.

A low-GHG fuel standard would incentivise the reduction of lifecycle GHG emissions of fuels. It would not directly incentivise other options ships have to reduce emissions, such as improving the operational efficiency of a ship. It would also not directly incentivise options to reduce the emissions of the transport system, e.g. by lowering demand for transport or increasing the size of ships. Nonetheless, because the standard would have an upward impact on the fuel costs, ever more options to improve the operational fuel-efficiency would become cost-effective, as would the business case for reducing emissions in the transport system. Hence the measure would indirectly have a positive effect on the energy-efficiency of ships.

The low-GHG fuel standard stands out in the selected measures by that it incentivises the uptake of low- and zero-carbon fuels from the start of the system, precisely because it only directly targets the emissions associated with fuel use. All other measures selected in this study would first incentivise the implementation of cheaper options before incentivising a fuel transition, which is more expensive than fuel options (IMO 2020). While in general it makes sense to start with cheaper options, the need to decarbonise in a few decades may require starting to address fuels from the start.

4.2 Operational GHG intensity standard

An operational GHG intensity standard sets a limit value for the GHG emissions per unit of transport work or similar indicator of the value it creates. Because the operational GHG intensity is related to the operational energy-intensity which varies with ship type and size, the standard would probably need to be a function of those parameters. IMO has agreed on a measure that would rate the CO_2 intensity of ships and reference lines are being developed for various ship types. Presumably, these reference lines can be used to set an operational GHG intensity standard. This means that the measure can be adopted as an amendment of MARPOL Annex VI.

Similar to the low-GHG fuel standard, the operational GHG intensity target would require there being an accepted way to establish lifecycle GHG emissions of fuels, in addition to accepted ways to determine the carbon intensity of a ship.

Similar to the low-GHG fuel standard, there are several ways in which the operational GHG intensity standard can be implemented, which has a bearing on how ships can comply:

- Ships can be required to comply with the standard on average within a certain compliance period. This means that they need to implement technical and operational energy-efficiency measures as well as choose fuels with a certain GHG intensity in such a way that at the end of the compliance period, the GHG emissions per unit of transport work (or other indicator of the value it creates) do not exceed the applicable limit value.
- Ships can be required to comply with the standard on average within a group of ships. In this case, credits could be granted to ships that overperform, e.g. have lower GHG emissions per tonne-mile. These credits can be surrendered by ships that do not meet the limit value. Ship types which have different units for the CII could probably not trade credits with each other unless equivalency between the units is agreed.

The standard could initially be set a little below the reference line and the stringency could be increased predictably over time to reach zero by the envisaged date for the phase-out of renewable fuels. While there is a clear case to be made for a reference line that varies per ship type and size, the case for varying the speed at which ships need to decarbonise is harder to make. Even though one could argue that some ship segments have a higher potential for efficiency improvement, the largest contribution to decarbonisation needs to come from changing fuels for all ship types.

The system is not primarily a revenue-raising instrument, but if there would be a need to raise revenues, this could be done by creating credits and selling them, while at the same time increasing the stringency of the requirements that ships need to meet so that the environmental objectives are still met.

An operational GHG intensity standard would incentivise all options to improve the GHG intensity of shipping, not just the fuel-related ones. Because energy-efficiency improving options tend to be cheaper, this means that the transition to low- and zero-carbon fuels will start after many energy-efficiency options have been implemented.

4.3 A standard-and-penalty scheme

Both the low-GHG fuel standard and the operational GHG intensity standard can be implemented as a standard-and-penalty scheme. This would imply that non-compliant ships would need to pay a penalty, which turns the measure into a revenue-raising measure.

The penalty could either be an alternative way of compliance (i.e. a non-compliant ships that has paid a penalty would not face further consequences) or not (in which case a non-compliant ship has to pay the penalty *and* find a way to rectify its non-compliance, e.g. by handing over credits after the deadline). The penalty could be set at a rather low rate in order to maximise its revenue or at a rate deterring ships from non-compliance.

In the current GHG-related regulations like the EEDI, the DCS and the SEEMP, enforcement is regulated in Regulations 5 and 11 of MARPOL Annex VI. Regulation 5 specifies that the Flag State shall carry out surveys of ships in order to enforce compliance with the regulations. Regulation 11 states that Port States may inspect ships in their jurisdiction and that they shall inform the Flag State if they detect non-compliance. In addition, they can take action against non-compliant ships under both national and international law.

The method of enforcement of either the Flag State or the Port State is not regulated under MARPOL Annex VI. Consequently one could argue that a standard-and-penalty system would introduce a new element. The legal options for doing so are beyond the scope of this report.

4.4 GHG emissions cap-and-trade system

A cap-and-trade scheme for maritime GHG emissions would set a maximum amount of these emissions, issue emission allowances up to that amount, distribute them over ships, and require all ships to emit no more GHGs than they hold emission allowances. By making the allowances transferable, the market should ensure that they are used by the ship which values them most. The maximum amount of allowances, the cap, could gradually be reduced to zero in order to ensure decarbonisation of the sector.

The requirement on ships is that they submit an emissions report to the Flag State or to a central organisation, and hand in a number of emission allowances equivalent to the emissions in the reporting period.

There are several ways in which ships could acquire allowances:

- Allowances could be distributed based on historical emissions of the ship. This would be feasible for existing ships, but it would mean that new ships either receive no allowances or that they receive allowances equal to an average comparable ship. The former would reward inefficient ships; the latter would require calculating average allowances units.
- Allowances could be distributed based on historical transport performance of the ship. Apart from the issue with new ships, this method of allocation would require that the transport performance of different ship types is somehow made comparable, which is not straightforward. Also, it could create inequalities within a sector such as bulk carriers, which sometimes transport high-density cargoes and sometimes low-density cargoes, and thus have a very different transport performance depending on whether it is measured in volume-miles or mass-miles.
- Allowances could be auctioned. This would ensure that the allowances are acquired by the ships (or on behalf of the ships) that value them most. The auction could either be organised by a central organisation, by Flag States, or by other organisations or States. The central organisation would thus generate revenues. Auctioning by Flag States would require a distribution of allowances over Flag States, which could be difficult to agree on. Other organisations could be climate finance facilities or climate vulnerable countries (CE Delft and TERI 2012).

The cap could be specified in MARPOL Annex VI together with the requirement that ships need to hand in allowances. It could be reduced to zero in a predicable way in order to allow the market to prepare. The existing data collection system may need additional safeguards against misreporting in order to ensure the integrity of the emissions trading scheme. Like the other measures, MARPOL Annex VI should also regulate how the GHG emissions of the ship have to be determined, taking into account both emissions during production, supply, and combustion.

An emissions trading scheme would incentivise all options to reduce emissions. Because energy-efficiency improving options tend to be cheaper, this means that the transition to low- and zero-carbon fuels will start after many energy-efficiency options have been implemented.

4.5 Emissions levy or tax

A GHG tax or levy would require ships to regularly pay a fee based on the quantity of GHG emissions by that ship. The tax could either be set directly at a level that renders the use of fossil fuels uneconomical or be gradually increased to that level so that renewable fuels, over which no taxes need to be paid, become cheaper to use than fossil fuels.

The tax could be based on emissions reported in the Data Collection System (which would then need to be expanded in order to include emissions of production and transport of fuels as described above). In case the tax is liable to the Flag State, payment could follow verification of the data collection report and the Flag State could issue a statement of compliance. In case the tax is liable to a central organisation, a system could be set up as introduced in the IMRF proposal by ICS et al. (2020, MEPC 75/7/4), which can be summarised as follows:

- Each ship is required to hold an account at the central organisation linked to its IMO number.
- Upon each purchase of bunker fuel, it transfers an amount to the account equal to the emissions associated with the purchase multiplied by the tax rate. Alternatively, the payment could be made at the end of the reporting period.
- Ships report their emissions to their Flag State as part of the DCS; the Flag State verifies the emissions report and submits it to the IMO DCS database.
- The central organisation checks whether each ship has complied by comparing the amount paid with the emissions reported in DCS database. When ships comply, the central organisation issues a statement of compliance which can be inspected by Port State Control.

Marginal abatement cost (MAC) curves of GHG reduction can provide important indications on what the level of the carbon price may need to be. MAC curves represent the relationship between the total reduction of GHG emissions and the cost efficiency for individual abatement measures, and show how much the marginal cost increases with additional abatement measures for GHG emissions in a given year.

Two different MAC curves have been developed for the Fourth IMO GHG Study based on two scenarios with higher and lower penetration rates of technologies, representing different assumptions on the presence of implementation barriers. The analysis finds that: 'Applying all the potential mitigation measures selected to all newly built ships from 2025, CO_2 emissions reduction in 2050 can achieve both IMO's mid-term and long-term reduction targets. The expected value of costs per year to achieve the maximum reduction is 257 USD/tonne-CO_2 towards 2050. In 2050, about 64% of the total amount of CO_2 reduction is contributed to by use of alternative fuel. (…) Use of alternative fuel with carbon contents has a higher positive value of MAC of > 250 USD/tonne-CO_2. Intending to use zero-carbon fuels, the MAC will increase to > 410 USD/tonne-CO_2, which is caused by the higher fuel price from synthesis process.'

ICS et al. (2020) argue that a revenue collection system can be implemented in MARPOL Annex VI. This is confirmed by O'Leary and Brown (2018) who argue that the IMO has broad powers to enact almost any measure. If that is the case, implementation through an amendment of MARPOL would require less time and effort than implementation through a new MARPOL Annex or a new convention.

4.6 Conclusion

This study has identified different measures that could be implemented in order to reduce GHG emissions of shipping by at least 50% in 2050 with a view to phasing them out as soon as possible in this century.

Before they can be adopted, each measure would require different barriers to be overcome. All measures would require better verification of emissions data in order to safeguard the environmental outcome, as well as a global registry either for credits, allowances or payments to facilitate enforcement. They would also require agreement on the emissions to be addressed and probably on how to assess emissions that occur prior to delivery of the fuel or energy source to the ship.

In addition, there are barriers which are specific to measures. A levy would require that states cede some of their fiscal autonomy to an organisation like the IMO or agree to coordinate national taxes closely. An emissions trading scheme would require agreement on the initial allocation of emissions. An operational GHG intensity standard would require agreeing on reference lines and reduction targets for each ship type. And finally, a low-GHG fuel standard requires acceptance of a focus on fuels.

5 Impacts of measures on States

5.1 Identification of ways to assess the impacts of measures on States

The 74th session of the MEPC approved the procedure for assessing impacts on States of candidate measures that can be proposed by member states and observer organisations as laid out in the MEPC.1/Circ.885 document. The procedure consists of up to four steps before the committee may consider the adoption of the measure:

Step 1: Initial impact assessment, to be submitted as part of the initial proposal to the Committee for candidate measures.
Step 2: Submission of commenting document(s), if any;
Step 3: Comprehensive response, if requested by commenting document(s); and
Step 4: Comprehensive impact assessment, if required by the Committee.

In the first step — initial impact assessment, as explained in par. 8.2 of MEPC.1/Circ.885 —, the procedure lists the need to identify which impacts should be assessed taking into account eight factors that are listed in the IMO initial strategy: (1) geographic remoteness of and connectivity to main markets; (2) cargo value and type; (3) transport dependency; (4) transport costs; (5) food security; (6) disaster response; (7) cost-effectiveness; and (8) socio-economic progress and development. Furthermore, it also requires an analysis of the extent of the impacts caused by the GHG reduction measure as described in par. 8.4 by e.g. quantifying them and relating them to relevant indicators such as transport costs, trade, or GDP. The comprehensive impact assessment, if required, would also need to include a detailed qualitative and/or quantitative assessment of specific negative impacts on States.

Given such requirements posed by the procedure, it is evident that each candidate measure proposed would require definitions of the factors that are considered for impact assessment i.e. how they can be measured (qualitatively and/or quantitatively), and taken into account in the assessment process.

This section aims to respond to the abovementioned requirements by providing a number of contributions. First, we provide the definitions for the eight factors that need to be considered for assessing the impacts of a candidate measure based on the literature. Furthermore, we specify the possible metrics to measure these factors. Second, we provide a review of different available models that can be used to assess the impacts of a GHG reduction measure together. Third, given the different available models, we develop a set of criteria to help evaluate the suitability of a modelling approach to assess the positive and negative impacts of a measure and answer the impact-related questions surrounding the adoption of the measure.

5.2 Specification of factors relevant for assessing impacts on States

5.2.1 Geographic remoteness of and connectivity to main markets

Geographic remoteness of and connectivity to main markets can be considered in different contexts of impact assessments. These factors could represent both performance indicators that are impacted by a GHG reduction measure and variables used to estimate the impact of a measure on other indicators such as trade flows (Fugazza and Hoffmann, 2017). To establish a clear scope of analysis we focus this section on the following question: 'How can we measure the impact of a measure on the geographic remoteness of and connectivity to main markets?'.

The notion of geographic remoteness has been specified across different domains and used interchangeably with remoteness such as in (Prabhu et al., 2013). For instance it has been used in international trade (Battersby and Ewing, 2005), transport (Taylor et al., 2006), and humanitarian fields (Wilbrink, 2017). Even though there are many methodologies that have been used to define remoteness, a typical remoteness index is generally constructed using distance as one of the basic components of the index. Geography, as the core discipline often used to define remoteness, generally takes into account the geographical distance between a location and the centre of an activity or service to describe the remoteness of a location.

Some of the most prominent indices for remoteness in the literature include:

1. The Accessibility/Remoteness Index of Australia - ARIA (DHA, 2001).
2. The remoteness index of UN's Committee for Development Policy (Social Council Committee for Development Policy, 2008).
3. The remoteness index for Canadian communities (Alasia et al., 2017).

In ARIA, the remoteness index is computed based on essentially the minimum road network distance between any population localities and the nearest service centres (i.e. any urban areas in Australia with population size more than 1,000 people). The size of a service centre is categorized into four classes depending on the population size of the urban area. Here the population size is used as a proxy to measure the availability of services. ARIA index is calculated by taking into account the road network distance from a locality to the nearest service centres with a certain category of service level and comparing it with mean road network distance of all localities to the nearest service centre with the same category. The ARIA score is used to provide a quantified measure of remoteness for all localities, where high score represents high remoteness and low score represents high accessibility.

The UN's Committee for Development Policy developed a remoteness index as one of the components of Economic Vulnerability Index (EVI). The EVI was used as one of the criteria for identifying Least Developed Countries (LDCs). A thorough explanation for EVI and LDC can be found in (http://www.un.org/en/development/desa/policy/cdp/cdp_ldcs_handbook.shtml). CDP defines remoteness as the trade-weighted average of the distance of a country from its world markets (Social Council Committee for Development Policy, 2008). The key components of the index are 1) the physical distance between a country and other countries 2) the market share of each trading partner of a country in the world markets.

Remoteness index for Canadian communities is computed based on two key parameters:

1. The proximity to all population centres within a certain radius limit that reflects accessibility on daily basis.
2. The population size of each population centre which is used as a proxy for availability of services. An important distinct feature in this index is the use of transport cost as a parameter that describes proximity between a community and a population centre. In this study, transport cost is mainly derived from travel time, the average annual operating cost of a vehicle, and the average speed of different transport modes.

Hence, in assessing the impacts of GHG reduction measures on remoteness we can draw several relevant key components from the previously developed indexes. In the context of maritime transport, the use of transport costs, as exemplified by the Canadian remoteness indicator, can be considered whenever the data is available. This is because transport costs can better represent other factors that are crucial in describing the impedance for transport between countries which has a high degree of variability such as the availability and the capacity of shipping services in a country, the quality and capacity of port and hinterland infrastructure, the travel time between countries that are determined by the schedules of the shipping companies. However, since transport costs data are not uniformly available for all States, especially for SIDS and LDCs, maritime travel time combined with value of time of specific cargos (whenever the data is available) can be used as a part of the metric to assess geographic remoteness.

Another relevant aspect is the market share or trade values between countries, as exemplified in the CDP study (Social Council Committee for Development Policy, 2008). Market share of the commodities traded by a country is useful to reflect the scale of the economic values of a country's trading partners. Hence taking a remoteness index of country x can be defined by taking into account:

1. The market share of country's x trade partners, i.e. the sum of import and export volume of the country from and to their trading partners.
2. The transport costs (whenever data is available) or travel time between country x to all of its markets combined with value of time of the cargo.

Similar to remoteness, connectivity is also a notion that has been extensively studied in the literature in different domains such as in air transport (Burghouwt and Redondi, 2013), and in maritime transport (Lee et al., 2016). The approaches employed in these domains have resulted in a diversity of determinants of connectivity which makes it hard to define connectivity in a universally coherent way (Calatayud et al., 2016). In other words, the precise definition of connectivity always depends on the context and the discipline within which it is applied. However, a systematic literature review of connectivity across different domains by Calatayud et al. (2016) concluded that there are three main perspectives that can help define connectivity:

1. Narrow: the availability and capacity of infrastructure and transport services and their ability to link supply and demand market.
2. Broad: the availability and capacity of infrastructure and transport services and efficiency of trade procedures.
3. Supply chain: the degree of information sharing among supply chain members.

Based on abovementioned definitions, connectivity is typically measured by specifying quantifiable indicators that together determine the level of connectivity of a geographical location. A relevant example of connectivity index in maritime transport which makes use of the narrow perspective is UNCTAD's Liner Shipping Connectivity Index (LSCI) (UNCTAD, 2018). This index takes into account five aspects that reflect the level of shipping services between two ports in two different States:

1. The number of container ships that connect the ports of the two States.
2. The container carrying capacity of the ships.
3. The number of services.
4. The number of companies that serve the connection between two countries' ports.
5. The size of the largest ship used to provide the service between two States' ports.

Another example of a connectivity indicator is a ship-type specific (RoRo ship) connectivity index proposed by de Langen et al. (2016). The author argued that Roro shipping requires a different methodology to measure connectivity. The following components are relevant indicators to define Roro connectivity:

1. The number of Roro destinations.
2. Service frequency (port calls).
3. Number of liner services.
4. Minimum number of intermediate stops.

In the context of impact assessment, the narrow definition of connectivity would be more suitable to be applied. This is because of number of advantages it offers such as 1) It will simplify the needs for data collection, 2) It will reduce the need to compute different indicators that need to be taken into account, 3) It allows to leverage the publicly available connectivity index that has been developed using empirical data such as UNCTAD's LSCI, 4) It helps to distinguish connectivity as a factor with a distinct definition that does not directly depend on the other factors of impact assessment.

Hence, the following indicators found in the literature (de Langen et al., 2016) can be considered as the core components that can be used to measure connectivity of a State.

Most of these indicators except transit time and number of transshipment can be found in the database that is publicly accessible to compute LSCI:

1. Vessel capacities (including maximum vessel size).
2. Service frequency (port calls).
3. Number of vessels deployed on services.
4. Number of liner services/directly connected ports.
5. Number of service providers.
6. Transit time.
7. Number of transshipments necessary for country-to-country trade.

Impacts on States connectivity can be evaluated by reflecting the changes in these indicators before and after a GHG reduction measure is applied using the formula defined by, for instance, UNCTAD's LSCI. In this way, the application of a measure such as carbon levy might cause changes in the networks of a liner shipping company which eventually leads to a change in one or more factors that constructs the definition of connectivity (such as service frequency, transit time, and number of transshipment). In order to estimate the changes in the liner shipping networks, a network design model needs to be deployed such as exemplified in (Dai et al., 2018). The use of such model also implies that the assessment of these indicators would require a dedicated modelling exercise that would require real data from relevant shipping service providers that connect States.

When access to such model is limited or unavailable, impact on connectivity can be assessed using scenario analysis. In this approach, changes in one or more indicators of connectivity can be estimated based on a given policy scenario and new connectivity score can be computed. This approach is less rigorous and may provide less accurate results than that which deploys a specific model but it also has the benefit of being more accessible and less resource intensive.

In light of the need to make impact assessment process efficient, using available metrics such as UNCTAD's LSCI to measure connectivity would be recommended. For non-containerized goods, additional variables such as transit time and number of transshipment might be incorporated into the connectivity metrics. Furthermore, for the sake of simplicity, it is also useful to combine the metrics for geographical remoteness of and connectivity to main market as in one assessment step. In such a case relative weights can be applied to both aspects to compute a new composite score.

$$CR_i = \alpha . CI_i + \beta . RI_i$$

where
CR_i = connectivity and remoteness score for State i
CI_i = connectivity index for State i
RI_i = remoteness index for State i
α = relative weight for connectivity index, $0 < \alpha < 1$
β = relative weight for remoteness index, $0 < \beta < 1$
$\alpha + \beta = 1$

5.2.2 Cargo value and type

We consider cargo value and type as factors that need to be taken in impact assessment rather than the factors, which impacts need to be measured. Therefore, In this section we address the following question: 'How can different cargo value and type be taken into account in assessing the impacts of a measure?'.

Cargo value and type affect the extent to which the increase in transport costs will affect the import prices of commodities. Commodities with high product value per ton will generally have lower relative transport costs or lower ad valorem rate — the proportion of transport costs relative to the total commodity value —, while commodities with lower value per ton will have higher ad valorem costs. Hence, an increase in transport costs due to the application of GHG mitigation measures might affect low value commodities more than high value commodities.

Furthermore, cargo type also determines the value of time (VOT) of the cargo — costs associated with the time it takes to transport the cargo from origin to destination. Cargo's VOT will in turn also determine the preferred mode of transport for the commodities. For instance, cargo with high perishability such as beverages, and food are more time sensitive than raw materials, hence their marketability would be more sensitive to change in the travel time. A similar case can also be seen in fashion products and high-end electronics where their availability at a certain time period is crucial which in turn may produce demand for high-speed transport services.

Given the variation in the proportion of transport costs in different commodities values and the different value of times of these commodities, impact assessment of GHG reduction measures ideally takes into account different commodity types and values. Specifically, impact assessment can take into account following attributes:

- The value of time (VoT) of different cargo types and their travel duration.
- The ad-valorem rate of different cargo types.

5.2.3 Transport dependency

Transport dependency reflects the extent to which a country is dependent on international maritime transport to sustain their economy and the livelihood of their citizens. States that are highly dependent on maritime transport may be impacted differently by measures than those that are not. Hence, to gain a better understanding on how transport dependency affects the impacts of a GHG reduction measure, we focus on the following question: 'What are the metrics that can be used to take transport dependency into account when assessing impacts of GHG measures? .

A study by Vivid Economics on the impact of a 10% increase in bunker prices shows that States that have a high share of sea import for their grain products, such as Kenya and Saudi Arabia, may see higher increases in import prices (Vivid Economics, 2010). This also implies that, States that are highly dependent on maritime transport (such as SIDS) to fulfill their demand for basic goods such as food items, energy, clothing, and housing materials may be more vulnerable to increase in transport costs and time. For instance, a reduction in shipping frequency that delivers basic commodities to these States might impact the availability and price of these commodities in the market, which in turn might affect the well-being and livelihood of the citizens.

Another aspect that can determine country's dependency is the availability of other modes that can serve as competitive substitutes to maritime transport to support trade between States. States with fewer alternative transport modes will typically be more impacted than those with more choices for transport modes.

Hence, based on the abovementioned factors, several important indicators for transport dependency can be synthesized:

1. The shares of maritime export and import in a country's GDP.
2. The costs and availability of other substitute modes to transport goods from and to the States.

5.2.4 Transport costs

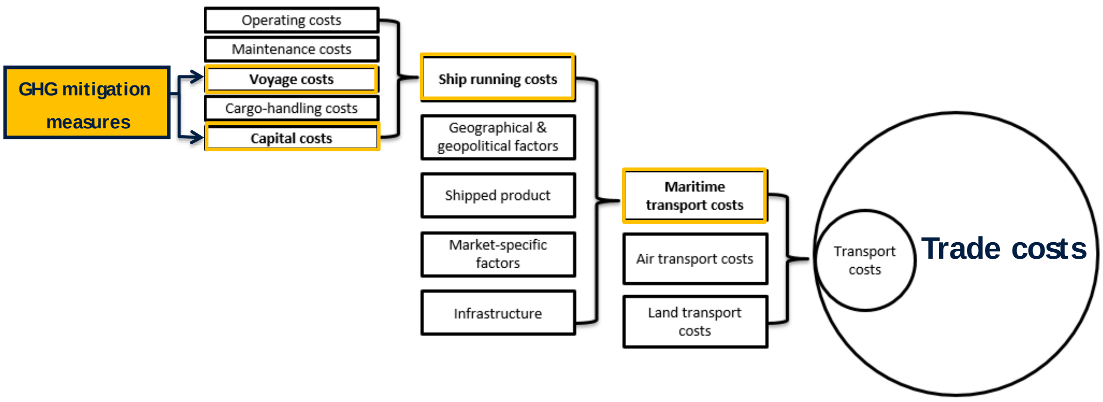
Transport costs are one of the main variables that can be used as a concrete indicator to measure the impact of the application of GHG measures. Investigating the impact of GHG mitigation measures on transport costs is of a high importance since the output of this assessment can feed into assessment of other factors listed in the IMO Initial Strategy such as disaster response, food security, and cost-effectiveness, and socio-economic progress and development. A salient example of how the impact of a change in transport cost change can propagate to the other factors is presented in (Halim et al., 2019). The author explained how increased transport costs might, in turn, affect the volume of trades between States. The change in trade volume can eventually affect many socio-economic variables of a country such as GDP, household consumptions, welfare, and employment. Hence, in this section we aim to address the following question: 'How can the impact of a GHG reduction measure on transport costs be estimated?'.

An application of a measure might increase transport costs in a rather indirect way. This is because based on the literature (Clark et al., 2004, Korinek and Sourdin, 2010, UNCTAD, 2015, Rojon et al., forthcoming 2019), transport costs are determined by several factors with differing weights such as:

1. Ship running costs.
2. Geographical and geopolitical factors.
3. Shipped product.
4. Market specific factors.
5. Infrastructure and services.

According to Rojon et al. (forthcoming 2019), GHG mitigation measures like carbon pricing could change two determinants of maritime transport costs: voyage and capital costs (Figure 2). Voyage costs are affected due to the short-term increase in fuel expenditures. Capital costs are due to the mid-/long-term adjustments in the design and technical specifications of ships that will be needed to reduce GHG emissions. Voyage costs can be estimated with reasonable accuracy using data on ship values, non-fuel and fuel operational expenditures (CE Delft 2019).

Figure 2 – Breakdown of maritime transport costs components



Source: Rojon et al. (forthcoming 2019).

This also means increase in transport costs due to a GHG reduction measure would not be uniform across commodities and routes globally. This is because other factors of transport costs for a given trade route such as port, and hinterland transport costs may have greater shares than ship running costs. It is also noteworthy that the impact of a GHG measure such as carbon levy on ship capital costs might be offset by investments in GHG mitigation technologies, which can help to gradually reduce the capital expenditures to adopt such technologies.

At present, transport costs data are commonly available in terms of freight rates (e.g. in USD/TEU or USD/ton), or Cost, Insurance, and Freight (CIF)/Free on Board (FOB) margin- the ratio between import costs that include costs of insurance and transport, and import costs that do not include costs of insurance and transport. Since trade (import) values data are available in CIF terms, transport and insurance costs can be estimated through the CIF/FOB margin of the import values in CIF terms.

However, currently there is not a transport costs database built on empirical data (such as those that can be obtained from customs or freight forwarder) that is complete (i.e.

datasets that include most transport routes between States globally) and publicly available. Some trade data for specific States are missing and limited to past records (e.g. OECD transport cost data[16] ends in 2007 and has not been updated since). Furthermore, there is an absence in some of these data sources for information on SIDS and LDCs, who may not have national statistics or reporting mechanisms. This is of particular concern, as the IMO sees a special need to consider the impacts of measures on these States (as noted by MEPC 68) and their emerging needs, as noted in resolution A.1110 (30) and in the IMO Initial Strategy.

In the absence of empirical data, estimation of transport costs data (e.g. by applying interpolation or proxies) is commonly performed such as exemplified in the OECD's International Transport and Insurance Costs (ITIC) data (OECD, 2017). The database is constructed using an analytical model that estimates the CIF/FOB margins of more than 1,000 commodities that are traded by more than 180 countries over the 1995-2014 time period. The model takes into account variables such as geographical distance, GDP per capita of both importing and exporting countries, infrastructure quality of importing and exporting countries, product value, contiguity and whether the trading countries are in the same continent.

Based on the components of transport cost found in the literature (Camisón-Haba and Clemente, 2019), and best practices to estimate transport costs, several key variables that can be used to predict the impact of a GHG measure on transport costs can be specified:

1. Maritime transport distance between origin and destination.
2. Cost of logistic operations such as port handling and transshipment costs.
3. Average ship running costs, which is explicitly broken down by capital and operational expenditures that include ship fuel costs/bunkering.
4. Commodities weights and values.
5. Travel time between origin and destination, which includes transshipment and ship dwell time, and hinterland travel time.
6. Trade balance of origin and destination country pairs.
7. Socio-economic indicators such as GDP, GDP per capita of both importing and exporting countries.
8. Infrastructure quality at origin and destination.
9. Value of time of commodity ¥ the equivalent monetary value for each time unit spent by the commodity during transport between origin and destination.

When the relative weights of these cost components are known, the impact of a GHG reduction measure on transport cost can be reflected in the change in one or more components of the cost (e.g. ship fuel costs for energy efficiency measure and travel time for speed reduction measure). Alternatively when access to the data for these cost components is limited, a more simplified approach is to estimate the change in transport cost based on a proxy such as change in ship running costs. In this approach, other cost components are assumed to remain constant.

5.2.5 Food security

According to FAO (Food and Agricultural Organization) (FAO World Food Summit, 1996), food security is defined as a condition where 'all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their food preferences and dietary needs for an active and healthy life'. Similar to transport dependency concept, in the context of impacts from GHG reduction measures, States that heavily rely on maritime transport to provide a secure access to food are more vulnerable to the changes in maritime transport services. To help study impacts of GHG measures on food security we focus our analysis on the question: 'How can the impact of GHG measures on food security be assessed?'

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[16] The OECD maritime transport cost database is compiled from CIF/FOB margins data obtained from customs and freight rates of 43 importing countries.

Based on the literature, the application of a GHG measure might result in:

- change maritime transport costs and import prices of food commodities;
- additional time needed to procure food commodities needed by a State (e.g. due to restriction on maximum operating speed of ships);
- alter the availability and frequency of shipping services due to changes in the networks of shipping liner companies.

A possible approach to assess the impact on food security is by firstly identifying countries that are vulnerable in providing food security to their population. To this end, we can utilize an international database that provides index on food security for countries globally such as that provided in (https://foodsecurityindex.eiu.com/Index). Next, a further investigation on the volume of food commodities imported by these vulnerable countries, particularly with maritime transport can be carried out. Countries with high vulnerability and high import volume of food commodities would be more likely to be affected by GHG reduction measures.
Among these identified countries, we can apply several relevant indicators to assess the impact of a policy measure on food security:

1. The share of food consumption in the average household expenditure of States. A substantial increase in prices of imported food, also caused by unavailable substitute commodities, might cause an increase in the average share of household expenditure on food products in a State. A considerable increase in household food expenses can reflect a negative impact on food security index of a country as shown by the findings in (https://foodsecurity index.eiu.com/Index).
2. The share of food imports in total food consumption.
   Food security can be negatively impacted when imported food commodities that are less likely to be substituted are less available. Hence an investigation can be focused on those commodities in vulnerable countries, especially where the food consumption is equal to or less than the recommended dietary intake.

5.2.6 Disaster response

According to UNDRR (United Nations Office for Disaster Risk Reduction), disaster response can be defined as 'actions taken directly before, during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected'. Since the relationship between a measure and their impacts on disaster response has not been extensively studied, this section is focused on the question: 'How can the impact of GHG measures on disaster response be assessed?'.

The implementation of GHG mitigation measures might impact the ability of a country to respond to a disaster, especially when the measures implemented could:

- Raise transport costs. Specifically, higher transport costs could increase the costs of taking immediate actions before, during, and after a disaster.
- Increase the time needed to deploy necessary mitigation actions to respond to a disaster (e.g. due to a speed limit regulation).
- Reduce the frequency of shipping services due to reduction in the volume of import/export commodities. This is because reduction in shipping frequency could increase the lead-time for procuring assets needed to support emergency response efforts.

This implies that States that are prone to disaster and highly dependent on maritime transport to deploy actions needed to mitigate the impacts of a disaster (e.g. distribution of goods and human resources), could be vulnerable to the impacts of a GHG reduction measure.

Hence, a potential approach to assess the impacts of a measure on States' ability to respond to disaster is by identifying States that are most prone to natural disasters and

further investigate the role of maritime transport in disaster response in those States. An international disaster database such as EM-DAT (https://www.emdat.be/) can be used to identify States which are prone to natural disasters and to analyse the indicators related to the occurrence of a natural disaster across countries globally. The database is established by the Centre for Research on the Epidemiology of Disasters (CRED). It records worldwide data on the occurrence and impact of over 20,000 natural and technological disasters from the year 1900–present. The database also contains statistical data that are useful to define an indicator of an impact such as the occurrence of disaster, total number of casualties, the number of population affected, and total economic damages across countries worldwide.
Several indicators that can be analysed to identify vulnerable countries can be extracted from the database. They include the share of economic damages due to disaster in the GDP of countries; the number of victims as percentage of the total population (Guha-Sapir et al., 2016). Furthermore, among the identified vulnerable countries, we can investigate the following indicators to assess the impacts of a mitigation measure:

1. The share of imported commodities crucial for providing disaster relief that is supported by maritime transport in the total economy of the States (GDP).
2. The modal share of maritime mode to transport goods that are crucial to mitigate the impacts of a disaster such as food, medicines, clothing, first-aid kits, tents, and emergency power supplies.
3. The total logistics costs to supply the demand for goods and services in the occurrence of a disaster. Note that total logistics costs referred here are broader than transport costs defined in Section 5.2.4 since this may include the inventory costs to provide the supply of goods. Total logistics costs can be estimated based on the time and costs associated with logistics operations to deliver goods under different disaster response scenarios. An example of quantitative analysis of these costs can be found in (Achurra-Gonzalez et al., 2016).

5.2.7 Cost-effectiveness

In the context of emissions abatement, cost-effectiveness is typically defined as the ratio between mitigation effect (i.e. emission reductions in the maritime sector) that can be delivered and the costs incurred to the economy of States to achieve that mitigation level. In this way, measures that deliver high mitigation potential (i.e. emission reductions) with low costs to the States will have high cost-effectiveness and vice versa.

One of the challenges in defining cost-effectiveness indicators is that it is highly dependent on the interests and perspectives of stakeholders that are represented by the indicator. Due to the crucial role of maritime transport in supporting global trade, mitigation policies in this sector may also influence other sectors that rely on maritime transport such as industries that depend on commodities traded globally and also the States whose economies might be impacted. Hence in this section we focus on addressing the question: 'How can we measure the cost-effectiveness of a GHG reduction measure?'.

A relevant metric for the States can be the ratio between GDP change and the total GHG emissions mitigated at the national level due to a GHG mitigation measure. Another example is the ratio between changes in commodities trade volumes and the total GHG emissions being mitigated from export and import activities. It is also noteworthy that GDP is an aggregate macro-economic indicator, which can be broken down into outputs of different industry sectors that contribute to the GDP figure. This means, it is also possible to construct cost-effectiveness indicators based on the ratio between weighted changes of outputs of the sectors and the GHG savings delivered by each sector in a State.

However, an important consideration for applying cost-effectiveness metric for States is the geographical level at which this metric is evaluated –i.e. a national or global level. In the context of achieving the initial IMO strategy's objective to reduce emissions from international shipping by at least 50% by 2050, analysis of the cost-effectiveness of the measures should be carried out at the global level. This is to prevent the implementation of measures that are cost-effective for individual States but not effective to achieve the global emission reduction target. For instance a global mandatory use of a certain alternative fuel such as liquefied natural gas might be less costly for certain States which have access to the natural resources and infrastructure for procuring this fuel, hence offering a cost-effective strategy for these States. However, this might not necessarily translate into a cost-effective strategy to attain global reduction of carbon emissions compared to other alternative fuel types such as hydrogen or ammonia-based fuels. Thus, the use of this metric also implies that there is no variation of impacts between individual States. The main benefit of this approach is to allow the comparison of the cost-effectiveness of different global measures. An example of this metric is the ratio between the global average of change in countries GDP and the total GHG emission reduction globally.

To address the disproportionately negative impacts of a measure to States such as SIDS and LDCs, a certain additional criteria can be integrated in the cost-effectiveness metric. For instance a threshold value for the change in the GDP of individual States can be established. In case the change in the GDP of SIDS and LDCs is above this threshold value, a mechanism for impact mitigation (such as investments in research and development, or exemptions) can be considered and the cost-effectiveness of the measure can be re-assessed.

5.2.8 Socio-economic progress and development

Socio-economic progress and development can be broadly defined and measured using several indicators depending on modelling exercises that are accessible. Hence, it is important to study and synthesize a specific metric to measure this factor. Hence this section is aimed to address the question: 'What are the indicators that can be used to measure socio-economic progress and development?'.

Some examples of the commonly used indicators are Gross Domestic Product (GDP), welfare, employment, and poverty level. Generally, estimation of a more comprehensive metric such as GDP requires more computation steps to account for all the relevant factors that contribute to the GDP such as private consumption, government investment, and spending, export, and import. On the other hand, more specific indicators such as export and import can be estimated using fairly established methods that can be found in the economic modelling literature.

Other indicators of socio-economic development and progress include spending by government on different services of socio-economic importance (e.g. infrastructure, health and education). A possible way to estimate socio-economic development of a country is by estimating economic growth of a country under a scenario where a GHG measure is applied and apply this economic growth factor to the medium term national budget planning for a specific country. The estimated government spending for public service sectors such as infrastructure, health and education, can serve as a metric for this factor.

Another indicator includes gender impacts, which could be inferred using more disaggregated household income data, whenever available. Changes in employments, income, and output of certain industry sectors that employ a certain gender due to a GHG mitigation policy might result in a reduction in the income of specific gender groups.

Table 10 – Summary of key parameters for each factor that need to be considered in impact assessment

Factor	Key parameters
Geographic remoteness of	1. The market share of a country in its trade partners, i.e. the sum of import and export shares of the country from and to their trading partners. 2. Time related costs or transport costs (whenever data is available) between a country to all of its markets.
Connectivity to markets	UNCTAD's LSCI index and for non-containerized products, the index can be augmented with: 1. Transit time. 2. Number of transshipments necessary to reach a country's trading partners.
Cargo value and type	1. Cargo's Value of Time (VOT) and cargo lead time 2. Ad valorem costs of the cargo, CIF/FOB margins of the cargo
Transport dependency	1. Commodities share of international export and import in a country's GDP, especially for commodities that are transported using sea transport. 2. The costs and availability of other substitute modes to transport goods from and to the States.
Transport costs	1. Maritime transport distance between origin and destination. 2. Cost of logistic operations such as port handling and transshipment costs. 3. Average ship running costs, which is explicitly broken down by capital and operational expenditures that include ship fuel costs/bunkering. 4. Commodities weights and values. 5. Travel time between origin and destination, which includes transshipment and ship dwell time, and hinterland travel time. 6. Trade balance of origin and destination country pairs. 7. Socio-economic indicators such as GDP, GDP per capita of both importing and exporting countries. 8. Infrastructure quality at origin and destination. 9. Value of time of commodity - the equivalent monetary value for each time unit spent by the commodity during transport between origin and destination.
Food security	1. The share of food consumption in the total household expenditure. 2. The trade volume of basic food commodities (such as wheat, crops) that are difficult to substitute.
Disaster response	1. The share of imported commodities crucial for providing disaster relief transported by maritime transport in the total economy of the States (GDP). 2. The modal share of maritime mode to transport goods that are crucial to mitigate the impacts of a disaster such as food, medicines, clothing, first-aid kits, tents, and emergency power supplies. 3. The total logistics costs to supply the demand for goods and services in the occurrence of a disaster.
Cost-effectiveness	1. Ratio between GDP change and the total GHG emissions reduced at the global level. 2. Ratio between changes in commodities trade volumes and the total GHG emissions reduced from export and import activities.
Socio-economic progress and development	1. Gross Domestic Product (GDP). 2. Welfare. 3. Employment. 4. Poverty level. 5. Government spending on public services (e.g. health, education, transport). 6. Gender impacts (income levels of different gender).

5.3 Review of methods for impact assessment

Given that each of the eight aspects can be defined based on broad factors, an attempt to apply one type of model to assess the impact of a measure on all these aspects simultaneously would be ineffective and difficult. This is because there is not a single model that can solely deliver on all possible impact assessment objectives. Some models would be more suited to assess certain aspects while the others would be more advantageous to estimate others. A more promising approach to assess the impacts of GHG mitigation measures would be to select a model based on the measure that will be applied and the specific main aspects that need to be assessed.
In this section we provide a review of several promising models that can be used to assess different aspects of the impacts based on their characteristics. The paper by Halim et al. (2019) provided a review of different models that can be used to assess the economic impacts of GHG mitigation measures together with advantages and disadvantages.

5.3.1 Regression model

A regression model is a statistical model that describes a mathematical relationship between independent variables and the estimated variable using observed data. Due to the flexibility in the way a regression model can be specified, it can be used to estimate short and medium term impact of a GHG mitigation measure on the majority of the aspects, provided that historical empirical data are available. A common application of a regression model is to describe the elasticity of trade, and demand for commodities with respect to changes in transport costs through the values of the coefficients of the model.

Based on the literature, one of the most relevant and valuable applications of regression models is to estimate the impact of a carbon levy on maritime transport costs. For this purpose, the model generally takes into account relevant variables such as ship running costs (e.g. fuel /bunker price, fuel consumption), geographical factors (e.g. time and distance), socio-economic (e.g. GDP, bilateral or multilateral trade agreement between States), infrastructure (port handling costs, and port-hinterland transport services), commodity-specific variables (e.g. value of time, average shipped volume, price of commodity, ship used to transport the commodities) and market specific variable (trade agreement, competition, and trade balances).

Another relevant application is to estimate the impact of changes in bunker price due to a carbon levy on trade volume of selected commodities. In this approach, transport costs data for different commodities and routes are needed as one of the independent variables. Other relevant independent variables would typically include all the factors that affect maritime transport costs as mentioned above. An example of a similar model that has been developed for this purpose is presented in (Martínez et al., 2015).

In the context of assessing the eight aspects of impact, estimation of the impact of a carbon levy on transport costs and trade volumes would provide the data needed to further analyse the other relevant aspects. This is because the metrics needed to measure other aspects such as food security, socio-economic progress, and development, cost-effectiveness, disaster response, transport dependency, can be derived from these two variables.

5.3.2 Input/Output (I/O) model

The I/O model represents the interaction and dependency between industry sectors by describing how the output (in monetary terms) of one industry sector may be used by the other sectors as an input for their production (Robson et al., 2018). Due to its structure, I/O models take into account several aspects of impact intrinsically such as different cargo types and values, and the connectivity to main markets, transport costs, and transport dependency. To estimate the impact of a GHG reduction measure on trade flows of commodities, a shock scenario needs to be formulated where transport costs and prices of commodities increase by a certain margin. The I/O model would then be able to assess the possible redistribution effects on trade flows under this shock scenario. The application of a carbon levy can be reflected in the transport costs variable that is normally used as a deterrence function in the gravity model component of the model. However, this also means that an accurate estimate of the possible increase in transport costs of different commodities due to a carbon levy is needed as an input. It is noteworthy that an I/O model has a limitation where it is unable to simulate the impact of a drastic commodity price or transport cost changes (Bachmann et al., 2014). This implies that I/O models should be used within a certain boundary of carbon levy levels. With regard to the other aspects of impact, the estimated trade flows can be used as an input to assess other factors such as disaster response, food security, socio-economic progress and development, and cost-effectiveness.

5.3.3 (Spatial) computable General Equilibrium models (CGE) model

A CGE model is a nexus of mathematical equations that represents the evolution of a whole economy and takes into account its macroeconomic constraints and the microeconomic behaviour of individual economic agents and their interactions. The CGE framework is built on modern microeconomic theory, which explains the conditions for economic equilibrium for all economic agents given certain demand and supply transactions. In CGE models, aggregate agents are used to represent the behaviour of the whole population or of an industrial sector as a single economic agent. These agents are modelled based on the assumption that they follow a cost-minimizing behaviour in performing their trade transactions. The price equilibrium conditions follow the basic market condition in which there has to be a balance in the demand and supply levels. The equilibrium is solved on a yearly basis and the model provides forecasted annual trade between economic agents as its output. A particular extension of the CGE modelling approach is the incorporation of a spatial dimension in its model specifications, which gives birth to the Spatial Computable General Equilibrium (SCGE) model. SCGE models are able to account for price differentiations between regions and specify transport costs as one of the determinants of trade flows between regions.

A scenario reflecting the application of a carbon levy on CO_2/GHG emissions can be simulated by incorporating an additional costs on transport costs based on the amount of carbon/GHG emissions emitted across the trade routes for each commodity group. In this way, several aspects of impact such as cargo type and values, transport costs, connectivity and geographic remoteness are considered in the application of a CGE model.

There are many outputs that a CGE model can produce to help assess the eight aspects of impacts. They include prices of commodities, household incomes, import and export volumes, GDP growth, and real GDP of States and the States' market share of their export commodities[17]. Import and export volume of States, prices of commodities, and household income can be used to assess food security, disaster response, cost effectiveness and socio-economic progress and development. GDP growth, and real GDP can be used to assess socio-economic progress and development, and cost-effectiveness. States' market share of their export/import commodities can be used to assess transport dependency.

5.3.4 Gravity model

A gravity model is an economic model that, in its traditional form, describes the volume of trade between two economic regions based on the size of their economies and the distance between them. Although distance has been generally used in the traditional form of the model as a factor that hampers trade, an augmented version of the gravity model can make use of other more comprehensive metrics that can allow the assessment of policy measures. These metrics may include transport costs for different routes and

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[17] SCGE models do not produce GDP as its direct output, but rather a variation of a welfare indicator that can be translated into a GDP prediction with additional assumptions.

commodities, or connectivity and remoteness metrics between two economic regions such as presented in (Fugazza and Hoffmann, 2017).

The impacts of a carbon levy on trade flows can be assessed by incorporating an increase in transport costs proportionate to this levy or by reflecting a change in the connectivity and remoteness indicators due to the increased transport costs. In this way, the gravity model can consider transport costs, geographic remoteness and connectivity, as well as cargo value and type. The estimated changes in trade flows can then be used to derive metrics for cost-effectiveness, social-economic progress and development, and food security.

5.3.5 Four step transport demand model

A four-step transport model is a typical model used to forecast transport demand on a transport network based on four computation steps that reflect the decisions of different stakeholders (economic agents, government, shippers, transport service providers) in a given transport network. The four computation steps in a transport model typically include: 1) trip generation, 2) trip distribution, 3) modal split, and 4) traffic assignment (Ortúzar and Willumsen, 2011). As such, this model is suited to assess the impacts of transport policies on transport choices of shippers. This model allows analysis on the distribution of freight traffic across available transport modes and routes under different scenarios that reflect policy measures applied both at infrastructure or individual shipper level (such as carbon levy).

In a transport model, policy measure such as carbon levy would typically be reflected in the variables that determine transport costs. Subsequently, an increased transport costs, due to the levy, will affect all aspects of transportation system such as the amount of goods produced and consumed between regions, trade flows between regions, the modal and route choices of the shippers and the distribution of the freight traffic on the available transport networks. Therefore, a transport model takes into account cargo value and type, and transport costs, and it can help provide metrics to assess the following aspects: connectivity and geographic remoteness (i.e. through observing the changes in routes and networks of the shippers), transport dependency (i.e. by evaluating the modal share for each of the commodity), cost-effectiveness, socio-economic progress and development, food security (i.e. by observing the changes in trade flows of the commodities, and its GHG emissions), and disaster response (i.e. by estimating the total logistics costs incurred to respond to a disaster under a given scenario).

5.3.6 Combined SCGE and four step transport demand model

Combined models merge SCGE and transport models in one framework to assess the impacts of policies in both transport and trade systems in a technically consistent manner. State-of-the-art models in this category typically use SCGE models to predict international trade and economic indicators of States — they essentially represent the first two steps of the four-step model e.g. trade generation and trade distribution. They integrate this with the rest of the four-step components, like modal choice, route choice, and traffic assignment models.

This modelling approach complements the analysis that can be performed using both transport and economic trade modelling. By using a combined model, the core behaviours of economic and transport systems can be assessed comprehensively. For example, for a given carbon levy, transport models can estimate the changes in modal and route choices of shippers and the resulting new transport costs due to changes in shipper's decisions. Subsequently, these transport costs can be fed into a SCGE models as a policy scenario that reflects the changes in the maritime transport sector. New transport costs would also affect trade between States in the model and the impacts of these adjusted trade costs on international trade flows can be simulated. The typical output of the combined model —spatial pattern of freight flows across routes and modes worldwide can be used to determine the total amount of global GHG emissions from shipping together with a ship emission model.

With regard to aspects of the impact assessment, combined models take into account geographic remoteness of and connectivity to main markets and different cargo values and types and they can be used to assess socio-economic progress and development (i.e. by computing indicators such as GDP, welfare, GDP growth, and poverty level), cost effectiveness (i.e. by comparing the change in GDPs of States and the GHG savings achieved), food security (i.e. by evaluating the changes in food commodity trade flows for States that are particularly vulnerable), transport dependency (i.e. by observing the share of international trade that is carried out by different modes of transport across commodities and the share of transport costs in the total product values).

Box 1 – The potential caveats of models for impact assessment

It is important to note that each model presented in this section might have been developed with specific set of objectives that motivated their development. Hence each model might have a different suitability to be used to assess the eight factors. In this section, we provide an example of the drawbacks of one of the models i.e. SCGE model and a summary of the way each model can be deployed to assess or take into account the eight factors.

An SCGE model is one of the models with higher level of sophistications due to the variables that are taken into account in estimating economic indicators of regions. They are typically used to assess the impacts of economic policies on the macro economic performance of countries. In this type of model, the specification of transportation system might be underrepresented (Robson et al., 2018) due to oversimplification of transport network and their responses to changes in transport costs. As a consequence, the accuracy of the outcomes of the model might be affected when the model is used to assess the impact of transport policies on the economy of countries (Shahrokhi Shahraki and Bachmann, 2018).

A well-documented caveat of a CGE model implemented in the GTAP (a widely used implementation of a CGE model) is the inaccuracy in modal share database of the model. Modal share data in GTAP is based on the US export data that is extrapolated to infer modal share data for trade activities for rest of the world (Gehlhar and McDougall, 1997). Since modal share data is used to derive international maritime transport cost margins and international maritime trade values, using the standard GTAP modal share data would lead to:

1. Inaccurate transport costs estimation for maritime transport. And
2. An underestimation of the total commodity values shipped by sea transport globally and consequently also an underestimation of the total carbon emission by sea mode (Nuno-Ledesma and Villoria, 2019).

To maintain a clear focus and scope, we do not provide exhaustive review of the strengths and weaknesses of each model. To help assess the suitability of each model in addressing each of the eight factors, we provide a summary of the relationship between different modelling approach and the eight factors in Table 11.

Table 11 – Summary of models and factors that can be assessed

Models (Row)/ Factors (Column)	Geographical remoteness of and connectivity markets	Cargo value and type	Transport dependency	Trans-port costs	Food security	Disaster response	Cost-effectiveness	Socio-economic progress and development
Regression								
Input/ Output								
Spatial Computable general equilibrium								
Gravity								
Four step transport demand								

Models (Row)/ Factors (Column)	Geographical remoteness of and connectivity markets	Cargo value and type	Transport dependency	Trans-port costs	Food security	Disaster response	Cost-effectiveness	Socio-economic progress and development
Combined SCGE and four step transport demand								

Legend:

Aspect which metrics can be fully assessed by the model

Aspect taken into account by the model

Aspect which metrics can be partially assessed with the model

Aspect which metrics are outside of model specification

5.4 Criteria for model selection

In this section we propose a number of criteria along with their relative importance (expressed in percentage) that can be used as a consideration in assessing the suitability of a model to be used to assess the impacts of measures on States. These criteria and their weights are formulated based on our findings from the literature review, and on the insights acquired from the stakeholder debate in and outside of the IMO while also taking into account the development of the ongoing IMO negotiations. These criteria and the weights, in essence, reflect the trade-offs that have to be made in selecting a model. For instance, models with higher number of parameters will have higher flexibility and versatility to reflect wider policy scenarios. Unfortunately, such models will also generally be more complex and costly to develop.

5.4.1 Transparency (20%)

It represents how easy it is to understand the structure of the model and the way it functions in producing output given a set of input.

5.4.2 Accuracy (15%)

This indicator defines to what extent a model is able to produce valid prediction results when compared to actual real world results.

5.4.3 Complexity (10%)

It refers to the expertise and time needed to specify, develop, and implement the model on a working platform.

5.4.4 Cost (15%)

It is defined by the amount of financial resources that is typically needed to finance the model development process.

5.4.5 Data requirements (20%)

It refers to the amount and type of data needed by the model to produce output and insightful information for policy makers. Different model specifications inevitably require different types and amount of data due to their structure and the kind of information they can produce as an output. Some of the data needed for modelling exercise are available due to previous data collection effort. However, some are not available since data collection has never been carried out before. This differing level of data availability makes it an important factor to consider in selecting a model to apply, as data collection effort can be very time consuming and costly.

5.4.6 Policy relevance (20%)

It refers to the ability of a model to test a wide range of policy measures using variables and causal relationships that can explicitly reflect the impact of application of GHG mitigation measures on the system.

6 Selection of methods to assess and address impacts on States

Chapter 4 explores the topic of impacts on States generally, including discussion of the IMO criteria and the different ways in which these could be modelled. Building on the analysis in Chapter 4, this Chapter focuses on the selection of a single method and defines how it can be applied to assess impacts and explores options for addressing impacts in the event they are identified to be disproportionately negative. In particular, it includes:

1. A framework to assess impacts on States based on a modeling exercise. And
2. Potential ways to address impacts on States.

6.1 Assessing impacts on States

The procedure listed in MEPC.1/Circ.885 document states that the impacts on States should be analyzed, for instance by means of quantification and relating them to normal variations in indicators such as transport costs, trade or GDP[18]. Furthermore it also requires the assessment of whether the measure is likely to result in disproportionately negative impacts and recommendations on how they could be addressed as appropriate[19].
To comply with these requirements, having a clear definition of impacts on States, along with negative and disproportionately negative impacts are important to clarify impacts being assessed. In this section we provide the definition of impacts on States based on the quantitative and qualitative metrics that have been defined in Chapter 4.

6.1.1 Framework to assess impacts on States

In order to establish a clear framework for assessing and defining impacts, we propose the use of the following definitions:

- Baseline scenario: also known as the 'reference' or 'no-policy' scenario is defined as future performance indicators of States, in which no policy measures are implemented apart from those which are already planned to be deployed in the pipeline.
- Net impacts: are defined as the future performance of States in terms of the indicators assessed in which both GHG reduction measures and impact mitigation measures are implemented next to policy measures that are implemented in the modelling.
- Negative impacts: are defined as net impacts which result in the negative changes in a country's impact indicators. Some of these can be presented as relative changes e.g. the changes in GDP are measured against the GDP of countries under baseline scenario.
- Disproportionately negative impacts are defined as negative impacts which fulfill certain criteria such as when:
  1) The negative change in the indicator assessed is above a certain threshold value (e.g. 1% compared to the baseline scenario).
  2) The negative change in the indicator assessed is above the average change of that indicator in a region which shares similar socio-economic characteristics.
  3) The negative change in the indicator exceeds the average growth rate of that indicator in a given time period (e.g. the expected impact is for significantly reduced per annum GDP growth relative to the average annual growth rate for GDP in the preceding decade).

[18] Based on the procedure for initial impact assessment Paragraph 8, point 4.
[19] Based on the procedure for initial and comprehensive impact assessment Paragraph 15, point 3.

6.1.2 Specification of eight impact areas on States

As explained in Chapter 4 not all of the eight factors specified in the Initial Strategy can be assessed by one modelling approach. In fact, most models are only able to analyse several impact indicators and take into account the remaining indicators in assessing impacts on States. As can be seen in Table 11, a common methodological approach among the majority of the models reviewed is to take into account the first four impact areas in impact assessment:

- **Geographic remoteness of and connectivity to markets:**
  - Remoteness and connectivity to markets can be reflected in the transport costs between a country to all of its market, and sum of import and export shares of the country from and to their trading partners.
  - Since sum of import and export shares are typically affected by transport costs, we consider transport costs as both an indicator of impacts as well as inputs to modelling, along with the impacts of a GHG measure on maritime transport costs. The outputs of a model therefore take the remoteness and connectivity of countries into account under different policy scenarios.

- **Cargo value and type:** is taken into account by considering the composition of a country's cargo types and the share of each type in the overall value of that country's trade. As also explained in Table 12, the transport costs or ad-valorem costs of the cargo can serve as an indicator which is taken into account by modelling.

- **Transport dependency**: is taken into account by considering the types of commodities that are transported by maritime transport in a country's trade portofolio. Furthermore, this aspect is also taken into account by considering the availability of the substitute **modes** and their associated transport **costs.**

- **Transport costs:** is typically taken as an explicit input into the majority of models. This is done through estimating transport costs that take into account the three variables above. In this way, changes in the three previous factors can be taken into account and its impacts can be reflected on transport costs of trade of commodities between country pairs. Alternatively, transport costs data can be obtained via establishment of observation data (a database) regarding transport costs:
  - Based on our assessment, transport costs –being one of first four impact areas, could represent impacts on the first three factors and serve as an initial indicator of impact. Hence, this implies when an increase in maritime transport costs exceeds a certain value (e.g. x%), we can consider this impact to be disproportionately negative.
  - On the other hand, transport costs are typically used as an input to a model to analyse the remaining 4 impact indicators that are more complex to measure and estimate. The impacts on States, therefore can be defined by focusing on the remaining 4 indicators in descriptive terms.

Food security

Based on the analysis provided in Chapter 4, the impact of a GHG reduction measure on food security is assessed on the basis of two related indicators:

- the share of expenditure on food consumption in overall household expenditure; and
- the share of food imports in overall food consumption.

The effects of changes in international maritime transport costs will be reflected in the changes in **trade flows** and specifically on **import of food products**. Data regarding materials for food products could also help to identify reliance on input materials or sector that are important for food production (fertilizers, machinery). Impacts on the imports of these input materials could have an effect on domestic and imported food

prices. In turn, the changes in the food prices may impact household's expenditure on food consumption.
Data sources on country-level food consumption and shares of expenditure can be gathered from various data sources. For the selected countries, these include data from the World Bank, OECD and country studies by national authorities on the share of food expenditure in overall household expenditure.
By comparing these indicators in a baseline and a GHG policy scenario, negative changes that reach a certain threshold (e.g. > 2%) in **food imports** can be considered as a disproportionate negative impact on States. Similarly, a negative change in the household expenditure on food consumption above certain threshold can be deemed as disproportionate negative impact.

Disaster response

As reported in section 5.2.6, disaster response refers to actions taken directly before, during or immediately after a disaster. Two aspects of disaster response effectiveness that can be assessed:

1. The extent of reliance on imported goods known to be crucial for providing disaster relief. These can include medicines, clothing, materials and machinery. Hence, it is useful to establish the list of goods that belong to these groups in the impacted countries. This can be done by reviewing significant disaster relief episodes in the relevant countries and identifying the key relevant imported goods.
2. The reliance on maritime transport for importing these goods.
   - Impact assessment on a country could compare the import of goods related to disaster reliefs under the baseline and policy scenario. If a country is vulnerable to disaster, as identified in the international disaster database such as EM-DAT, then a negative change in the import of these disaster relief goods can be evaluated. A negative change above a certain threshold may render the impact to be disproportionately negative.

Cost-effectiveness

As observed in section 5.2.7, cost-effectiveness can be measured through various metrics. For the purpose of assessing impacts on States, it is proposed to examine the relationship between the proposed level of abatement pursued via a particular GHG reduction measure and the incidence of costs as reported in the other aspects.
The proposed metric to be used is the ratio between the costs or the 'net impacts' as defined by the metrics specified for the other aspects (i.e. food security, disaster response, socio-economic progress and development) and the total GHG emission reduction globally.
Unlike other aspect, costs effectiveness does not pertain directly to the definition of impacts but rather to the efficiency of the proposed GHG policy measures (which include both GHG reduction and impact mitigation measures). Hence the ratios produced are typically used to aid decision-making through comparing the performance of different policy scenarios. For instance, policy measures that have low or positive net impacts and high GHG abatement would be preferable over measures that have high net impacts and low GHG abatement potential.

Socio-economic progress and development

As observed in section 5.2.8 this aspect can be described by broad indicators. Among different indicators compiled in Table 10, Gross Domestic Product (GDP) is frequently used as a headline indicator of socio-economic development. Analysis on other indicators such as welfare, employment, and gender impacts can be done by evaluating the detailed impacts of a measure on the output broken down by specific industry sectors. Hence to analyse impacts on this aspect comprehensively, the quantitative analysis will need to be supplemented by a description of distributional issues. The analysis may have a particular focus on sections of the countries' population and society that may be exposed to adverse change in the sector's outputs.
There are several ways to define a disproportionately negative impact to a State's GDP.

That is when:

1) The negative change in the GDP of a State is above a certain threshold value (e.g. 1% compared to the baseline scenario).
2) The negative change in the GDP of a State is above the average change in GDP of a region which shares similar socio-economic characteristics.
3) The negative change in GDP of a state exceeds the average growth rate in a given time period (e.g. average annual growth rate for the preceding decade).

6.1.3 Synthesis of main indicators for assessing net impacts on States

Based on our assessment above, we can synthesize common indicators, which can represent impacts on the eight aspects listed in the Initial Strategy. They are:

1) Transport costs, considering economic emission intensities for each source and destination route.
2) International trade value by modes of transport, particularly sea transport.
3) Outputs of economic sectors in each relevant State.
4) Gross Domestic Product and employment.

Hence in assessing impacts on States, we will evaluate the variation of the above indicators by means of comparison against performance in baseline scenario. Whenever appropriate and necessary, detailed indicators for each of these aspects, covering specific geographical regions such as SIDS and LDCs can be derived from the analysis on the impacts of these common indicators.

6.2 Addressing disproportionally negative impacts on States

In this section we provide a description of possible ways to address disproportionally negative impacts of policy measures on States. Furthermore we also provide an assessment for the impact mitigation measure that will be incorporated as a scenario evaluated using the modeling exercise in Chapter 6. In general impact mitigation approaches can be based on:

1. Exemption or differentiation from the GHG reduction measure.
2. Revenue redistribution system built on a revenue-generating policy.

6.2.1 Specific exemption or differentiation from GHG reduction measures

Route based exemption

An exemption from GHG reduction measures can be based on routes that are applied to specific regions, such as some SIDS/LDCs that rely significantly on sea transport. This aims to avoid the negative impacts on these secluded countries, i.e. the loss of their trade relationships with other economies once the measures are applied. Route based exemptions can be applied to different types of GHG reduction measures such as market based measures (MBMs), or operational measures (such as reduction in speed). Route-based exemption can be applied to, for instance, speed reduction measure. In this application, regions that are eligible to be exempted from speed reduction measure are allowed to be served by ships with relaxed speed restriction. This measure works by firstly understanding that transportation between origin and destination can be seen in series of routes. According to this concept, it would be desirable to apply the conditional speed limit with adaptation based on routes that pass through certain exempted areas. Route-based exemptions can either be introduced tacitly, e.g. through non-enforcement of speed restrictions on these routes, or officially by agreeing on the exemption of certain routes (Anger et al., 2013).

On the other hand, there is also possibility of market or trade distortion due to route-based exemptions. For example, ships that would need to maintain the same travel time to reach their destinations could divert from its original routes and choose to sail on the exempted routes to gain time advantage. This is because lead time of a shipment might have an impact on the market share of certain commodities (i.e. longer travel time might cause certain commodities like food products and perishables to lose their market). This could, in theory create a market distortion and hamper the reduction of GHG emissions.

A weakness of route-based exemption is that it may mean that countries with exempted routes experience poorer quality shipping services. Ships with lower efficiency may be deployed due to the exemption, leaving these routes 'locked in' to higher fuel costs. Furthermore an exemption means that the investment needed to assist in the transition is postponed, potentially meaning the country gets 'left behind' on important technology and economic development.

Cargo type and volume based exemption

Another exemption measure is cargo type and volume-based exemption. This exemption aims to ensure the shipment for specific cargo types will not burden the performance of specific industry sectors. For instance, cargo quality and security are important in the shipment of food products. The effort to achieve emission reduction may increase fuel costs, and in turn, this may result in ships reducing their speed to save fuel consumption. Longer lead time due to reduced speed may affect the quality of food product since they might deteriorate over time. Another example is shipment of health equipment and medicine. Within the health industry, punctual arrival of disaster response equipment, health equipment and medicine can be a vital requirement to ensure an adequate supply for meeting the demand in a timely manner.

The measure works by allocating the emission calculated for the shipment to each cargo type and not to the ship owners. The plausible drawback of this exemption is the complexity of the administrative procedure (which involves emission calculation for each cargo type based on the routes travelled and volume) between ship owner, regulator, and the shippers (e.g. food or health industry). In container shipping this may be impracticable as container ships often carry a mix of different cargoes.

In terms of volume based, exemptions could be given to relatively small ships due to their small contribution to the total GHG emission (Faber et al., 2009). This will also help regions which infrastructure capability is small, for instance regions with small ports, berths, or limited water depth.

The main concern of this exemption is in setting an effective threshold for the ship volume, which can effectively help reduce carbon emissions while supporting operation of small ships especially to underdeveloped regions. This is because this exemption might incentivize the use of relatively smaller ships, which may harm the emission reduction objective.

Ship type and age categories based exemption

This exemption primarily targets ships of a certain type or age to be exempted from GHG reduction measures. This measure poses a considerable administrative complexity for its successful implementation. This is because ships of the same type could have a wide variation in their emission intensity (i.e. volume of GHG emission emitted per tonne-kilometer) due to their age, size and condition. Hence, excluding a certain ship type without more detailed specifications could have negative implications on emission reduction goals. Exemption based on ship type might be applicable for a certain ship type that only contributes to a small fraction of global ship fleets. This, in theory, should not affect the efficacy of GHG reduction measure strongly. For instance, Faber et al. (2010) proposes that an exemption of certain types such as ferries or general cargo ships, would only reduce undesired impacts on developing countries if these countries are predominantly served by ships of certain types.

However, since the variety of ships used across developing countries are very high, it is very difficult to apply uniform exemption measures solely based on ship types. For instance, this exemption might not be beneficial to developing countries that are served by varying ship types due to the heterogeneity in the commodities they import and export. Hence the drawback of this measure is in the complexity of the eligibility conditions that can promote fair exemption mechanism.

Exempting ships that belong to a certain age category (e.g. older ships) may also have a trade-off. On one hand, it may help reduce the compliance costs of shipping companies with many old ship fleets and promote a fair compliance condition. On the other hand, this might not create a proper incentive for ship owners to scrap older ships which are less fuel efficient and safe than newer ships. In turn, this could reduce the effectiveness of the GHG reduction measures.

A notable exemption that might promote the reduction of GHG emissions is exempting ships that are still relatively young or compliant with high fuel efficiency standard from the policy measures. However, in this case, smaller shipping companies with lower capital to acquire newer ships might be disadvantaged than bigger shipping companies with higher capacity to acquire newer ships.

Differentiation

A variant of exemption is differentiation. Instead of completely removing any mitigation policy from the route, cargo/volume, ship type/age, for any variant of mitigation policy options considered in Chapter 1, a different level of stringency is applied for a subset of the differentiation category. For example, ships on some of the routes pay a different carbon levy per tonne of emissions to ships on other routes. The advantages and disadvantages of this option are broadly aligned to if a full exemption is applied to the category.

Phased implementation

Similar to route based exemption, phase implementation can be applied to most GHG reduction measures. The main mechanism of this measure is to exempt ship fleets that meet a certain criteria from achieving a mandatory carbon reduction target and to gradually alleviate this exemption according to a predefined timeline.

An example of phased implementation is demonstrated in the implementation of IMO's EEDI (Energy Efficiency Design Index) standard. A study by Shi, Y. (2016) introduces a phased approach for the implementation of (EEDI) based on policy negotiations at the IMO. The purpose of EEDI is to deliver environmental benefits by generating, through enhanced energy efficiency measures, significant reductions in GHG emissions from ships (IMO, 2012). The phases are divided into four. The first phase (2013-2014) is called a two-year grace period, in which all ships regardless of their flags are relaxed from all EEDI measures. In the second phase (2015-2019) the reduction level of carbon emission is set to 10% and this will be adjusted as the technology development shows its growth. Furthermore, in the third phase (2020 onwards) new technologies and design speed reduction will be utilized more to meet the EEDI standard. In, the last phase (2025 onwards), a 30% reduction level of carbon is set for most ship types with the reference line of ships built between 2000-2020.

Another example can be found in the implementation of a measure in the aviation sector - CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation).
The scheme has three phases, which begins with voluntary participation from states, and then gradually followed by participation of all States except those exempted from offsetting requirements. The phases consists of:

- pilot phase (2021 -2023) which will apply to all States that have volunteered to participate in the scheme where they can choose to apply offsetting to:
  - an aircraft operator's emissions covered by CORSIA in a given year; or
  - an aircraft operator's emissions covered by CORSIA in 2020.
- first phase (2024 -2026) which will apply to States that have volunteered to participate in pilot phase and any other States which decide to participate;
- second phase (2027 -2035) which is applicable to all States with:
  - an individual share of international aviation activities in Revenue Tonne Kilometers (RTKs) in year 2018 above 0.5 per cent of total global RTKs or

– whose cumulative share in the list of States from the highest to the lowest amount of RTKs reaches 90 per cent of total RTKs[20].

least Developed Countries (LDCs), Small Island Developing States (SIDS) and Landlocked Developing Countries (LLDCs) are exempted unless they volunteer to participate in this phase.

6.2.2 Redistribution systems based on revenue generating policy measures

The basic principle of this system is redistribution of fund based the revenues generated from any policy measures targeted to reduce emissions from international maritime transport. To coordinate the redistribution mechanism effectively and transparently, the revenue from these measures can be collected and distributed by a centralized institution such as a GHG fund administrator. These revenue generating policy measures have been described in Chapter 3, which cover the following:

1. Levy.
2. ETS.
3. LCFS.
4. Baseline-and-penalty: penalties for non-compliance (noting that a system of penalties may not create predictable or centralized revenue in the same way as other options, so may not be viable for redistribution).

A requirement for this impact mitigation measure is that there is a revenue generation system that can allow an accumulation and redistribution of funding. In theory this redistribution system could help facilitate countries in emission reduction efforts. The policy can be implemented in the medium term (as laid out in the candidate medium-term measures in the IMO initial strategy), which can help developing and transition countries to adapt to the impacts from GHG reduction measures. The concept of revenue redistribution is not new relative to existing literature. For example, there have been various studies which indicate the advantages of revenue redistribution systems based on carbon price (Sewalk, 2014; Parry et al., 2018; Kachi et al., 2019).

The utilization of the revenue to address disproportionate negative impacts on States

Under this scheme, the revenues collected from carbon levy could be used in different ways that could address the potential negative impacts from the application of the levy. Technically, revenues collected can be used to fund the following initiatives:

- Capacity building and technical cooperation
  For example, the revenues collected could partially be spent to fund R&D activities, which could help the development of promising low-carbon shipping technologies (Acemoglu et al., 2016). For instance, investments in R&D aimed to improve the fuel efficiency of ships could reduce the economic impact of MBMs on countries, especially SIDS/LDCs. Ships can become 25-75% more efficient than they currently are by applying a range of operational and technical improvements produced by R&D (Bouman et al., 2017). This funding can be also directed to support research in developing countries to increase the economic viability of low-carbon technologies such that adoption of these technologies can be accelerated among countries that are impacted negatively.
  In the EEDI standard developed by the IMO, there are several technologies that are expected to be developed for emission reduction. They include lightweight construction, hull coating, gas fueled (LNG), hybrid electric power and propulsion concepts, up to wind and solar power (Shi, 2016). Since the achievement of the target set in the IMO initial strategy would benefit from the compliance of the shipping sector across the globe, advances in low-carbon shipping technologies are therefore expected to be implemented as wide as possible. However, in

[20] Based on the definition of CORSIA retrieved from https://www.icao.int/environmental-protection/pages/a39_corsia_faq2.aspx

practice, technology improvement may not be equally accessible for all ship owners, especially for those located in SIDS/LDCs or developing countries. Capacity improvement and technical cooperation therefore could play a significance role in finding a balance between realizing emission reduction of each shipping company while at the same time supporting SIDS, LDCs, developing and transition countries to catch up with the technology development needed. In planning steps of energy efficiency actions, Shi (2016) also adds that human resource development is also one of the relevant elements. Nevertheless, capacity building and technical cooperation may not be a straightforward approach that directly provides short-term benefits to the mitigation of negative impacts.

Investment in the shipping servicing disproportionately negatively impacted states

Revenues could be disbursed preferentially to ships servicing disproportionately negatively impacted states. This could be a variant of one of the design options explored in Chapter 3, which uses revenues to subsidise mitigation, in this instance gearing the revenue to subsidize shipping operations that serve disproportionately negatively impacted States. For example, revenues could be used in a concept known as 'contracts for difference', which has been used in some instances as a means for governments to support investment into renewable energy. It guarantees a return on an investment with high upfront costs, long lifetimes and volatile or uncertain wholesale prices. Applying this concept to IMO GHG policy could involve a centralised fund contracting with fuel suppliers to cover the difference between the market price for a fuel and the levelized cost of production. The advantage of this system is that it mitigates the costs borne by shipping companies due to the reduction in ships emission. This reduction in costs could, in turn, mitigate the increase in transport costs to States that are disproportionately negatively impacted and abate the wider impacts of such transport costs increase (i.e. increase in import prices of goods, and reduced international import/export flows).
Another advantage is that it allows the shipping company to receive funding that can be instrumental for improving fuel-efficiency (such as by investing in newer more efficient ships). However, as the carbon efficiency of the relevant and global shipping fleets improves, the revenue flows will also change due to the adjustments in the volume of ships emissions. This may reduce the mitigation effects on the States that are disproportionately negatively impacted by the GHG reduction measures. Therefore, the policymaker should be aware of this plausible setback of the system. In order to ensure that the measure addresses disproportionate negative impact effectively, a monitoring, reporting and verification system with a periodic review might need to be established. This system should monitor and evaluate the emissions of shipping companies servicing States that are negatively disproportionately impacted as well as the additional costs born by the shipping companies associated by these emissions. The amount of the investments directed to the shipping companies should be adjusted based on the outcome of the periodic review (e.g. every three years). In this way, reduction in carbon emissions due to improvements in ship's efficiency would reduce the amount of revenue reinvested into shipping companies. In contrast, when the emissions from ships are not reduced then further investigations can be carried out to determine whether the investment needs to be continued. The goal of the system is to gradually phase out the investment in greener and cleaner ship operations over a predefined period of time (e.g. ten years).

Investment in port and hinterland infrastructure

More efficient port and hinterland transport infrastructure can help reduce total logistics costs associated with international trade. Wilmsmeier et al. (2006) conclude, that port efficiency is the most important element of international transport costs in Latin American countries. A model-based analysis undertaken by Tavasszy et al. (2011) finds that port costs strongly determine a port's attractiveness and competitiveness in attracting international cargo. Besides port infrastructure, port-hinterland infrastructure also strongly determines the total transport costs. Hinterland transport costs, on average, constitute 80% of the total transport cost of intermodal shipment, while hinterland transport covers only 10% of the total transport distance (Rodrigue & Notteboom, 2012). Thus, investing in port and hinterland infrastructure could help reduce total international transport costs. In this way, the rise in maritime transport costs due to carbon levy can be mitigated by reduction in port logistics costs (such as handling costs, supply chain costs for low-carbon fuels) and hinterland transport costs.

Investment in climate fund for mitigation and adaptation activities

Parry et al. (2018) proposes the use of Green Climate Fund to allocate revenues collected from levy to mitigation and adaption activities in developing countries. This scheme can be extended to specifically fund mitigation and adaption activities in LDCs/SIDs that are disproportionately negatively impacted by a GHG reduction policy. This does not in itself resolve negative impacts, but may be seen as a 'value transfer' to disproportionately negatively impacted states to act as a counter-balance to those impacts.
Mitigation activities may include research projects and programmes that can improve the fuel efficiency of ships, or help cut emissions from shipping through the development of alternative low-carbon fuels, or shipping technologies.
Adaption activities may include i) development of vital infrastructure (road, bridges, ports, shipping services) that are severely impacted by severe weather events; ii) subsidies for sectors and jobs that suffer from reduction in outputs due to climate change (e.g. agriculture, livestock, forestry and fisheries industries); iii) provision of health facility, food and water supplies for impacted communities.

Direct financial aid for disproportionately negatively impacted countries

Another option is to disburse the revenues as a financial aid to countries that are negatively impacted by the levy. For example, revenues could be distributed based on countries' reduction in GDP or reduction import and export values. This is done because increase in maritime transport costs may translate to increased import prices of goods (Halim et al., 2019) which may lead to the decline in countries' import values (e.g. due to reduced consumption of imported products) and export values (i.e. due to possible loss of export market). The financial aid can be directly given to the treasuries of countries that are negatively impacted when they meet certain eligibility criteria, to offset negative economic consequences. A consensus among the IMO member countries might be needed to determine these criteria.

6.2.3 Assessment of mitigation measures for addressing impacts on States

To help assess the efficacy of each mitigation measure to address negative impacts on States, we develop evaluation criteria which consists of the following:

1. **Risk of carbon leakage**
   This refers to the extent to which the mitigation measure is prone to escape strategy that might be deployed to avoid complying with the GHG reduction measure. This avoidance may reduce the efficacy of the reduction measure or even an increase in total GHG emission.
2. **Risk to progress in green technological transition**
   This refers to the extend to which the measure incentivizes the retainment of currently deployed shipping technologies to reduce capital and operational costs of the shipping business. In turn, this may cause a lock in effect where the technological transition and of countries served by these ships may be impeded.

3. **Potential to counterbalance negative impacts (e.g. poor for capacity building)**
   This criterion considers the ability of the mitigation measure to directly address negative impacts on States, especially for developing countries, SIDS, LDCs due to implementation of a GHG reduction measure.

4. **Ease of monitoring of impact mitigation (e.g. poor for direct financial aid)**
   This criterion measures the extent to which the mitigation can be easily supervised, accounted, and the costs associated with this monitoring the measure.

5. **Administrative burden to implement the measure**
   This refers to the complexity and costs associated with administrative process of implementing the measure such as costs of:

- publishing and promoting the measure;
- setting up licensing and registration systems;
- determining appropriate tax/levy rates (for estimating the revenues needed for addressing negative impacts on states);
- determining the thresholds and terms of the measure (such as rules applicable for exemption based measure);
- accounting the amount of emissions associated by shipment of goods and the revenues lost or generated related to that shipment;
- evaluating R&D subsidy proposals.

Based on our assessment, revenue redistribution measures perform relatively better than exemption/differentiation based measures. This is because exemption/differentiation based measures have caveats that are not difficult to address and thus, may harm the achievement of emission reduction objective. They generally require complex administrative procedure and they are also prone to carbon leakage. In turn, this could lead to a rise in global GHG emissions from international maritime transport.

Among the possible options to redistribute the revenues accumulated from a GHG reduction policy, we consider investment in climate fund, and port and hinterland infrastructure as the most promising measures. They both have high potential in preventing carbon leakage and negating the negative impacts on States. Hence, to draw on the strengths of both measures, the revenues generated from a policy measure can be reinvested for climate fund and targeted port-hinterland infrastructure development whenever possible. This hybrid approach could help:

1) Accelerate the decarbonization of maritime transport by reducing the costs of low-carbon technologies and increasing its economic viability.
2) Abate the negative economic impacts of the levy in a targeted and effective manner (i.e. through the development of port hinterland infrastructure).

6.2.4 Selection of mitigation measures tested in modeling exercise

Testing the impact of various mitigation measures imposes complex modeling requirements that will have to take into account a lot of uncertain factors. In fact, not all mitigation measures can be modeled within the scope of this project due to the uncertain nature of the measures (such as capacity building and technical cooperation). Hence, to allow a quantitative assessment of the impact mitigation scenarios in the subsequent chapter, we assess the scale of impact mitigation based on a several assumptions:

1. The revenue redistribution system is assumed to be inclusive of any of the reinvestment options regardless of the policy instruments used to collect the revenue.
2. The revenue is distributed and used in the most effective way possible.
3. The redistribution is assumed to fully counteract the negative impacts whichever ways the fund is disbursed e.g. if the disproportionate negative impact is estimated as a $100m reduction in GDP relative to no a scenario where no policy was applied, then the value of the funds for redistribution is assumed to be $100m.

It is recognized that this results in a significantly simplified approach for quantifying the cost of addressing negative impact on states. And further work to develop methods on this is likely to be required.

6.3 Selection of modeling approach for assessing net impacts on States

The guideline for impact assessment procedure in MEPC.1/Circ.885 requires that assessment should be simple, inclusive, transparent, flexible, evidence-based and measure specific. Chapter 4 has explored different possible modeling approaches that could be used to assess impacts of policy measures on States. Furthermore, we also proposed a set of criteria that may be used to assess the suitability of each modeling approach. In this section, we assess the suitability of each model identified in Chapter 4 and propose one model to be applied for assessing the net impacts of policy measures on States. In line with the guideline for impact assessment procedure, the model selection takes into account the following main factors:

1. **The type of GHG reduction measures that are going to be deployed**
   We study measures that would result in increase in maritime transport costs. For modeling simplicity, we consider measure such as GHG tax as a policy measure that can represent the impact of variety of measures on a key variable such as maritime transport costs.

2. **The type of impact mitigation measures used to address the negative impacts of the measures**
   We estimate quantities for the revenue redistribution system as a mitigation measure for a subset of countries that are negatively impacted. We consider this measure to be representative of the effect of a wide array of measures that can be used to mitigate the impacts of increased transport costs on the indicators we analyze.

3. **The type of indicators that are going to be assessed:**
   As mentioned in Paragraph 4.1, we study the following indicators:
   - transport costs, considering economic emission intensities for each source and destination route;
   - international trade value by modes of transport;
   - outputs of economic sectors in each State;
   - GDP and employment.

These factors become relevant in model selection because the assessment is focused on the resulting 'net' impacts of both GHG reduction and impact mitigation measures. Furthermore, although a variety of models are able to assess the same measures and indicators, they differ in terms of their transparency, accuracy, complexity, cost, data requirement, and policy relevance. Hence, to systematically assess the suitability of each quantitative model assessment process, we take into account the abovementioned factors as the underlying context for assessing model's suitability and we use the criteria identified in Chapter 4 to score and establish ranking for the models. We use a 1-5 scale for each criterion, where 1 denotes the least score, indicating weak suitability and five denotes the highest score indicating a strong suitability. Table 12 provides the overview of scoring for each model and its total score.

Table 12 - Evaluation of different models for assessing net impacts of policy measures

Model/ Criteria	Transparency (20%)	Accuracy (15%)	Complexity (10%)	Cost (15%)	Data reqs (20%)	Policy relevance (20%)	Score	Rank
Regression	5	2	4	3	4	3	3.55	4
Input/ Output	3	3	3	4	3	3	3.15	6
SCGE	4	5	2	3	4	5	4	1
Gravity	3	3	3	4	4	4	3.55	3
Four step transport demand	4	3	2	3	3	5	3.5	5
SCGE + four step transport demand	4	5	2	2	3	5	3.65	2

Based on our assessment, most models have a decent score with SCGE model considered to be the most suitable modeling approach to assess economic impacts on States. This is followed by a combined SCGE+four step transport model (called 'combined model') in the second position. The differentiating factor between the two models is due to the combined model being more expensive, and data hungry than SCGE model.
Despite having a relatively low score on cost and complexity, both models have a relatively high score on accuracy and policy relevance criteria. The later are crucial considering the type of measures being tested and the indicators being evaluated. The following key reasons describe comparative strengths of the models which lead to their relatively high score and rank:

1. **Ability to capture substitution behavior of the consumer market**
   SCGE model is able to capture the substitution behavior of the consumer market that may be caused by increase in transport costs. That is, States could substitute consumption of imported commodities with those that are produced locally or originated from nearer producers. On a global scale, this substituting behaviour may result in the redistribution of trade volume which in turn could impact the import and export volumes of countries and their GDP.
2. **Ability to simulate the wider economic impacts of increased transport costs**
   SCGE models are able to take into account the interaction of different industry sectors while taking into account macro-economic feedbacks such as potential change in import prices of goods due to increased maritime transport costs. Hence, they excel at estimating the longer-term evolution of economic variables in a technically consistent manner. Furthermore, SCGE models are typically able to produce multiple economic indicators of interest, such as GDPs,[21] trade flows, commodity prices, and welfare in a single run.
3. **Ability to simulate impact mitigation measure such as feebate mechanism**
   Unlike other economic models, SCGE or CGE models such as GTAP allow the specification and testing of revenue redistribution in conjunction with the implementation of GHG reduction measures in the same scenario. Hence, the model is able to estimate the net impacts of the measures on indicators such as GDP, trade flows, employment, and transport costs.

6.4 Further model development to assess the impacts of GHG mitigation measures

In this section we describe model developments that have been incorporated to address the caveat of the GTAP model identified in Task 3. In addition, we also describe possible extensions of the model which could enable more detailed assessments on the aspects listed within the IMO's strategy.
Specifically, the need to further develop the GTAP model stems from the limitation of the model to account for mode specific transport costs in estimating global trade. This functionality is relevant to assess the impact of increased maritime transport costs due to GHG reduction measures (e.g. carbon levy) on indicators such as trade volume and GDP. Unlike GHG reduction measures, mitigation measures such as direct compensation package given to treasuries can be modeled using standard GTAP model specification.

6.4.1 Model developments to assess the impacts of increased maritime transport costs:

1. **Computation of mode specific transport cost**
   An important modification of the GTAP model needed to assess the impacts of changes in maritime transport costs is on the computation of modal shares among modes of transport relevant for transporting commodities in international trade. This modification is needed to address the caveat of the model as explained in

21 SCGE models do not produce GDP indicators as their direct output but they are able to produce such indicators with additional assumptions, please also see footnote 2.

Paragraph 4.3. Estimation of modal shares for different trade relationships is crucial to minimize inaccuracies in estimating transport costs for individual modes (air, maritime, road, rail) and in estimating the values of commodities transported using maritime transport.
In this project, we modify the GTAP-E model from Avetisyan (2018) with transport mode substitution to incorporate exogenous changes in transport costs by commodity, transport mode, and source-destination country pairs. In this way, the changes in the cost of maritime transport can be incorporated into GTAP model, and the amount of transportation services necessary to transport a given product along a particular route through a given mode can be estimated.
The modal substitution in the model is described by Avetisyan and Hertel (2020), which incorporates modal substitution into the standard GTAP model (Hertel, 1997). There are three transport industries in the model: Other Transport, Water/Maritime Transport, and Air Transport. As mentioned by Avetisyan and Hertel (2020), estimated estimated elasticities of modal substitution for land-air and water-air transport pairs explain the mechanism that governs modal substitutions among these modes.

2. **Computation of economic emission intensities for international maritime transport**
In the GTAP model it is impossible to distinguish between domestic and international transport emissions. Therefore, calculating international emission intensities per dollar of transport services output (economic emission intensities) directly from the GTAP emissions data will result in inaccurate estimates, since these economic emission intensities will include both sources of transportation emissions. Additionally, the lack of domestic transport margins in the GTAP model makes it even more difficult to differentiate between domestic and international transport emissions.
In this project we develop a methodology to separate the domestic and international elements of transport emissions. We then calculate the economic emission intensities of international maritime transportation for each region pair, enabling more accurate estimation of changes in transport costs for each route driven by the long-term emission abatement measures for international maritime transportation.
More specifically, we develop the following steps involved in a comprehensive assessment of economic emission intensities of international maritime transportation in the GTAP model:
   - Use the value of transport services output by region and the value of exports of water transport services by source and destination region to compute the share of exported maritime transport services by route in the total maritime transport services output.
   - Apply the share of exported maritime transport services to maritime transport emissions generated in each region, and then divide it by the cost of maritime transport to ship goods from the source to destination region.
   This methodology enables more accurate estimation of economic emissions intensities of maritime transport by source and destination. It should be noted that due to the GTAP database limitations (availability of transport emissions for each good shipped from a source to destination region) we are not able to generate the maritime transport economic emission intensities by commodity, source and destination.

6.4.2 Further extensions for the GTAP model to assess detailed net impacts of GHG reduction measures

An approach that has gained some prominence in addressing the limitations of GTAP model is by combining it with a four-step transport demand model or called the combined model. In our assessment, this model is ranked second to SCGE models due to its added cost and data requirement. However, if higher details and accuracy are of priority (i.e. to assess a specific economic impacts on specific region and specific commodity group

levels), the application of this model can be considered. Please see (Halim et al., 2019) for examples of the application of combined models.
In the context of assessing impacts of GHG reduction measures, further extensions of the GTAP model may include the following several additional modules which enable the application of the Activity, Structure, Intensity, Emission Factor (ASIF) framework (Schipper et al., 1999) to estimate GHG emissions as well the eight impact areas in a technically consistent and robust manner. These modules encompass freight transport demand model and ship emission estimation model as follow:

1. **Mode choice model**
   Combining mode choice model with the GTAP model will allow a more accurate estimation of modal shares across all major modes for international trade. A mode choice model is typically built using statistical theory (such as discrete choice modeling) and empirical observation data. This model is designed to predict the modal share of different modes for trades of commodities between country of origins and destinations. Thus this model could help increase the accuracy of calculation of international maritime transport costs under different policy scenarios.

2. **Route choice model**
   Route choice models can be used to estimate the activity of international maritime transport (in tonne-kilometers) based on the GTAP projection of the volume of international trade between countries globally. Furthermore, they can also be used to estimate maritime transport costs under different policy scenarios that may affect total lead-time of freight shipment from origin to destination (e.g. through reduction in border passing time or cargo handling time at ports) or total transport costs (such as through the application of carbon levy based on the activity of the ships). In turn, this estimate of maritime transport costs could provide a detailed and accurate input for GTAP models to estimate the impacts of changes in transport costs on global trade volume and the GDP of countries.

3. **Ship emission estimation model**
   A ship emission estimation model would enable a robust estimation of GHG emissions translated based on the activity of international shipping projected using GTAP, mode-choice, and route choice models. This provides several advantages:
   - The projection of GHG from international maritime transport can be consistently validated with other projections and differences in underlying assumptions to estimate GHG emissions can be verified.
   - The impact of GHG reduction measures on emissions and its mitigation measures can be analyzed at a detailed geographical level such as on shipping routes between origins and destinations, at a national level and for different commodity groups. In other words, the methodology would enable the more accurate estimation of carbon emissions associated with each route and the impact of policy measures on each trade route between countries across commodities studied.

6.4.3 Global Trade Analysis Project (GTAP) Model : modeling framework to assess net impacts on States

Until recently, the input-output (I-O)[22] and macroeconomic growth (MG)[23] models have been the main approaches to estimating the economic impacts of energy and environmental policies. The varying scope, methodologies and assumptions of these models limit the comparisons that can be made between their results. Although input-output models provide information about direct and indirect economic effects, those lack the behavioral component and are not able to provide information about prices and markets. Using computable general equilibrium (CGE) models for such analysis enables

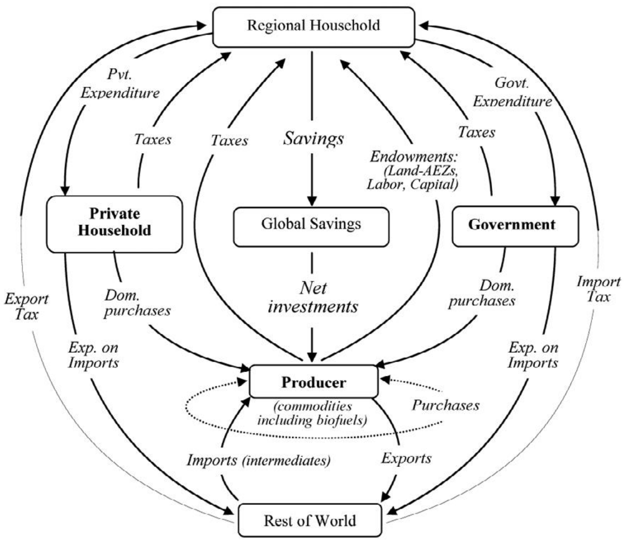
[22] See Miller and Blair (2009).
[23] See Kydes et al (1995).

the researcher to get a more disaggregated picture (more commodities) of the economy-wide effects, providing sector wide information about direct and indirect economic effects.
CGE models have been extensively used for analyzing trade and transport-related policies. Among available models which use CGE framework, GTAP model is presently the most extensively used international CGE model. This model was developed in conjunction with the U.S. International Trade Commission (ITC) and the World Trade Organization (WTO). Pilegaard and Fosgerau (2008) analyze the impact of reduced transport costs on increased employment search over longer distances using a spatial CGE model. Sandoval et al. (2009) develop a CGE model of the world economy to study the possibility of hydrogen transportation and trade under different carbon stabilization and tax policy scenarios. Winchester et al. (2013) use a recursive dynamic CGE model to analyze the impacts of a representative carbon policy on U.S. aviation operation and emissions. Finally, a recent study by Avetisyan (2018) analyzes the effects of global carbon taxation on international trade and transport mode choice in international trade, and subsequent changes in international transport emissions. The author modifies the Energy-Environmental version of the Global Trade Analysis Project (GTAP-E) model to allow for substitution among different transport modes.
The aim of using GTAP methodology in this study is to on one hand provide sector wide information about direct and indirect effects of changes in maritime transportation costs, and on the other to balance the need for simplicity with the need for comprehensiveness.

Incorporation of modal substitution module to model maritime transport costs

In the GTAP model, the origins and destinations are specified for traded goods but not for transport services. The latter are aggregated into a single Global Transport Services Industry, and then allocated to different importing countries based on the share of exports of traded goods (non-margins) for each country in the global exports of traded commodities. Specifically, when a commodity is shipped from the source to the destination country, the exported commodity at FOB price is joined with the composite international transport good (which represents a mix of air, maritime, and other transport modes) to generate the CIF price of this commodity in the destination country. The structure of the standard GTAP model is summarized in Figure 3.

Figure 3 - Structure of the GTAP model



Source: Hertel et al., 2010.

In GTAP transportation price variables ($PTRAN_{i,r,s}$ and PT_m) are endogenously determined. More specifically, $PTRAN_{i,r,s}$ is the price of composite transport services in Global Transport Services Industry for shipping good *i* from source *r* to destination *s*, and PT_m is the price index of global transport services by mode *m*, which is not differentiated by industry, source, or destination.

In our modified version of the GTAP-E model, the international transport cost is differentiated by mode of transport and is expressed as a percent change variable $ptrans_{m,i,r,s}$. This is made possible through incorporating modal substitution model represented by CES (Constant Elasticity of Substitution) that is estimated using observation data on relative prices of different modes of transport. The estimation result found CES value between 0.57 to 2.1 which governs modal shifts between water, air, and other transport modes. In most economic sectors the modal substitution elasticities between water and air transport dominate the elasticities of substitution between land and air transport modes (Avetisyan et al., 2015; Avetisyan, 2018; Avetisyan and Hertel, 2020).

Using this version of the model, an emissions taxation of water transport can be modeled by perturbing maritime transportation costs for each good transported from the source to destination country. This will result in transport emissions changes and modal substitution governed by a CES elasticity of substitution in Equation (1):

$$TRANS_{m,i,r,s} = EXP_{i,r,s} * TRTECH_{m,i,r,s}^{(\sigma_{i,r,s} - 1)} * \left(\frac{PTRAN_{i,r,s}}{PT_m}\right)^{\sigma_{i,r,s}} \qquad (1)$$

where:

$TRANS_{m,i,r,s}$ is the international use of transport mode *m* to ship good *i* from region *r* to *s*;
$TRTECH_{m,i,r,s}$ is the transportation technology of mode *m* to ship good *i* from region *r* to *s*;
$EXP_{i,r,s}$ is the export sales of commodity *i* from region *r* to *s*;
$\sigma_{i,r,s}$ is the elasticity of modal substitution to ship good *i* from region *r* to *s*;
PT_m is the price of composite transportation services;
$PTRAN_{i,r,s}$ is the price of international transport to ship good *i* from region *r* to *s*.

Since the equations in the GTAP model are linearized, we modify Equation (1) to express it in linear percent change form, as shown in Equations (2) and (3):

$$trans_{m,i,r,s} = -trtech_{m,i,r,s} + exp_{i,r,s} - \sigma_{i,r,s} * \left(pt_m - trtech_{m,i,r,s} - ptran_{i,r,s}\right) \qquad (2)$$

$$ptran_{i,r,s} = \sum_m [TRSHARE_{m,i,r,s} * \left(pt_m - trtech_{m,i,r,s}\right)] = \sum_m ptrans_{m,i,r,s} \qquad (3)$$

where:

$trans_{m,i,r,s}$ is the percent change in international use of transport mode *m* to ship good *i* from region *r* to *s*;
$trtech_{m,i,r,s}$ is the percent change in transportation technology of mode *m* to ship good *i* from region *r* to *s*;
$exp_{i,r,s}$ is the percent change in export sales of commodity *i* from region *r* to *s*;
$\sigma_{i,r,s}$ is the elasticity of modal substitution to ship good *i* from region *r* to *s*;
pt_m is the percent change in price of composite transportation services;
$ptran_{i,r,s}$ is the percent change in price of international transport to ship good *i* from region *r* to *s*.
$TRSHARE_{m,i,r,s}$ is the share of transport mode *m* in cost to ship good *i* from region *r* to *s*;
$ptrans_{m,i,r,s}$ is the percent change in the price of international transport mode *m* to ship good *i* from region *r* to *s*.

When international maritime transport costs increase due to external factors not included in the model, such as emission tax, the transport cost variable $ptrans_{m,i,r,s}$ needs to be 'swapped' with another variable to maintain the balance between the equations and endogenous variables in the model. Thus, we use a variable representing the change in shipping technology to transport goods from source to destination country by specific mode of transport. Ideally, the value of this now endogenous technological variable would remain zero or near zero, since we do not change the technology of maritime transportation.

GTAP Database and Aggregation

In this study we employ the Global Trade Analysis Project Energy-Environmental (GTAP-E) version 9 database, which contains detailed information on energy usage and carbon dioxide emissions by origin and sector, and can be used for performing simulations reflecting changes in international maritime transport costs.

At its maximum disaggregation, GTAP-E version 9 consists of 140 country economies, each of which is comprised of 57 traded and non-traded sectors, and incorporates the import/export trade and transport linkages between them. Although it is computationally infeasible to run simulations with the fully disaggregated 140 country/region and 57 sector version of the model, the GTAP database can be easily aggregated to fewer regions and sectors enabling a comprehensive analysis of particularly interesting subsets of the full dataset. In our analysis, we aggregate the model to 51 regions (representing 2601 bilateral trade pairs) and 29 sectors. The detailed regional and sectoral aggregation is provided in Tables 13 and 14.

The choice of this specific aggregation serves several objectives. First, one of the goals of our project is to analyze the impact of increased maritime transport costs on the Small Island Developing States (SIDS) and Least Developed Countries (LDC) defined by the United Nations, thus we match some of these countries with those available in the GTAP-E version 9 database and preserve them in the aggregated database. Second, we also analyze the impact of increased international maritime transport costs on low and high income countries defined by the World Bank, and therefore in our regional aggregation we also preserve a subset of these countries that we are able to match with the original GTAP-E data base. Finally, our sectoral aggregation is designed specifically to maintain the original food sectors, while aggregating other sectors in the GTAP-E model, since our assessment of potential impacts of increased maritime transport costs on states also addresses the supply and security of food in different countries.

Table 13 - Regional aggregation

#	Regions
1	United States
2	Canada
3	European Union
4	Japan
5	China, Hong Kong
6	Brazil
7	India
8	Russia
9	Oceania countries
10	Dominician Republic[a]
11	Jamaica[a]
12	Puerto Rico[a]
13	Trinidad and Tobago[a]
14	Cambodia[b]
15	Lao People's Dem. Republic[b]
16	Malaysia and Indonesia
17	Singapore[a]
18	Afghanistan, Bhutan, Maldives[c]
19	Bahrain[a]
20	Benin[b]
21	Burkina Faso[b]
22	Guinea[b, c]
23	Togo[b]
24	Mauritius[a, c]
25	Mozambique[b]
26	Rwanda[b, c]
27	Uganda
28	Zambia[b, c]
29	Ethiopia[b, c]
30	Nepal[b, c]
31	Bangladesh
32	Madagascar[b, c]
33	Malawi[b, c]
34	Senegal[b, c]
35	Tanzania[b, c]
36	Zimbabwe[c]
37	Other East Europe and Rest of Former S. Union
38	Rest of European Countries

#	Regions
39	East Asia
40	Rest of South East Asia
41	Rest of South Asia
42	Rest of Oceania
43	Rest of Carribean
44	Central and Caribbean Americas
45	South and Other Americas
46	Central Africa[c]
47	Rest of Eastern Africa[c]
48	Rest of Western Africa[c]
49	Sub Saharan Africa
50	Middle Eastern and North Africa
51	Rest of the World

a. 7 SIDS(https://sustainabledevelopment.un.org/topics/sids/list)
b. 17 LDC (https://www.un.org/development/desa/dpad/wp-content/uploads/sites/45/publication/ldc_list.pdf)

Table 14 - Sectoral aggregation

#	Sectors
1	Paddy rice
2	Wheat
3	Cereal grains
4	Oil seeds
5	Sugar cane, sugar beet
6	Other agriculture goods
7	Forestry
8	Raw milk
9	Cattel, sheep, goat, horses
10	Non-ruminant livestock
11	Processed dairy products
12	Processed ruminant meat products
13	Processed non-ruminant meat products
14	Vegetable oils and fats
15	Beverages, tobacco, sugar
16	Processed Rice
17	Food products other
18	Other primary products: Fishery & Mining
19	Coal
20	Crude oil
21	Natural gas
22	Petroleum, coal products
23	Electricity
24	Energy intensive Industries
25	Other transport
26	Water transport
27	Air transport
28	Other industry and services
29	Services generating Non-CO_2 Emissions

Model validation

One of the focuses in model validation is on the model's ability to reproduce impact of changes in transport costs on mode shares is relevant to ensure that the model is able to reflect the impact of changes in transport costs on modal shares and use of different transport modes.

Avetisyan and Hertel (2020) provide validation of their modified version of the GTAP-E model by analyzing the historical changes in world trade facilitation and their effect on transportation, by mode, between 2007 and 2012.Specifically, they run the historical 'trade facilitation' simulation using the exogenous factor productivity changes when the world economies and Logistics Performance Index (LPI) grow within the 2007-2012 period. Some countries produce high value products and require better logistics for fast shipping of such goods via air transport. Additionally, the demand for air transport may increase due to growing demand for 'just in time' delivery of intermediate products. After observing the changes in transport services output they validate the revised version of the GTAP model focusing on the measurement error.

To what extent does the simulation based changes in transport services use differ from historical changes in the use of various modes of transport? To answer this, Table 15 compares GTAP-based trade facilitation simulation estimates of air and other transport services use changes against those calculated based on the World Bank, World Development Indicators[24] (WDI) data on air and other transport services usage[25,26] combined with their unit cost estimates available from Hummels et al. (2009), and distance data from CERDI and CEPII databases, where available.

As shown in Table 15, growing LPI and economic growth in most regions will increase the use of both air and other transport with relatively larger increase in air transport use in some regions. Also the comparison of air and water transport services shows that growing LPI results in increased air transport use in about 85% of regions. The change in water transport services is not shown in Table 15 due to WDI data limitation on water transport use.

Table 15 - GTAP simulation based and historical changes (2007-2012) in air and other transport services by region and mode, percent

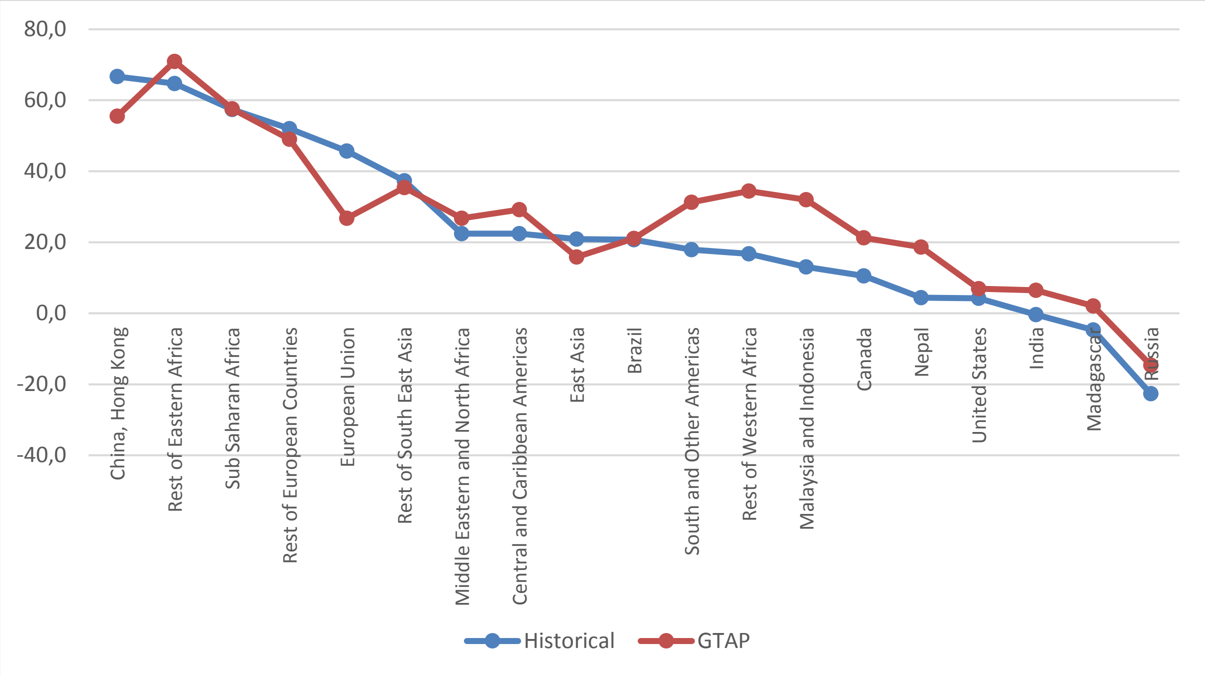
Region	Air transport		Other transport	
	GTAP	Historical	GTAP	Historical
United States	7.0	4.2	4.5	6.9
Canada	21.3	10.5	16.5	16.3
European Union	26.7	45.7	29.1	35.5
China, Hong Kong	55.5	66.7	61.6	59.0
Brazil	21.1	20.7	21.9	25.6
India	6.5	-0.4	4.1	-1.0
Russia	-14.6	-22.7	-19.0	-22.7
Nepal	18.6	4.4	12.2	9.2
Madagascar	2.1	-4.7	-6.0	1.3
Rest of European Countries	49.0	52.0	52.3	60.0
East Asia	15.8	20.9	11.8	20.2
Rest of South East Asia	35.4	37.3	38.7	21.1
Malaysia and Indonesia	32.0	13.1	32.8	35.6
Central and Caribbean Americas	29.2	22.4	24.9	19.7
South and Other Americas	31.3	17.9	30.7	26.7
Rest of Eastern Africa	70.9	64.7	35.8	30.9
Rest of Western Africa	34.4	16.8	35.8	23.1
Sub Saharan Africa	57.6	57.4	67.0	66.6
Middle Eastern and North Africa	26.7	22.4	26.8	28.1

The findings reveal that the historical improvement in logistics decreases the total cost of transport and amount of services necessary to ship a given good along a given route by a given transport mode. Reduction in modal cost also leads to modal substitution. The

24 http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators
25 https://www.gtap.agecon.purdue.edu/databases/v8/default.asp
26 https://www.gtap.agecon.purdue.edu/databases/v9/default.asp

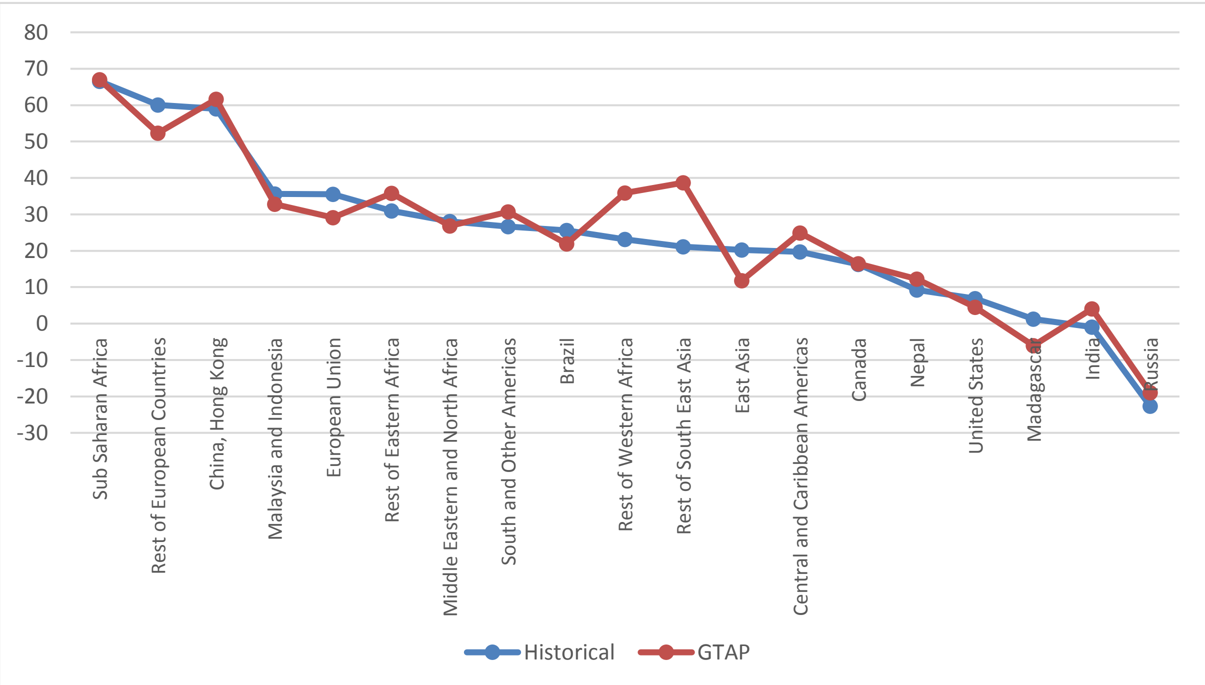
model validation shows that both historical and GTAP based changes in air and other transport use across regions show strong agreement in most cases. The comparison of historical and GTAP based changes (2007-2012) in air and other transport use is illustrated in Figures 4 and 5.

Figure 4 - GTAP simulation based and historical changes in air transport services output, (percent)



Source: Avetisyan and Hertel (2020).

Figure 5 - GTAP simulation based and historical changes in other transport services output, (percent)



Source: Avetisyan and Hertel (2020).

In case of air transport we find strong agreement in United States, Canada, Rest of European Countries, Central and Caribbean Americas, Brazil, Russia, India, East Asia, Rest of South East Asia, Madagascar, Sub Saharan Africa, Rest of Eastern Africa, and Middle Eastern and North Africa. This indicates that the change in logistics was a dominating factor in the expansion of air transport services in these regions.

In the case of other transport services the two series show strong agreement in United States, Canada, South and Other Americas, Central and Caribbean Americas, Brazil, European Union, Rest of European countries, Russia, China, Hong Kong, India, Nepal, Malaysia and Indonesia, Madagascar, Sub Saharan Africa, Rest of Eastern Africa, Middle Eastern and North Africa, emphasizing the importance of logistics changes in the development of other transport services in these regions.

In some regions there are variations between the GTAP simulation based and historical estimates of air and other transport use changes within the 2007-2012 period. This is especially interesting for the Rest of Western Africa region, which shows relatively larger differences for both air and other transportation. In this version of the GTAP model Rest of Western Africa includes twelve countries and regions. As mentioned in the GTAP version 9 (year 2011) data base documentation, some of the data sources for these regions are based on earlier data with different reference periods for regional I-O tables[27]. This is due to the availability of I-O tables in these countries that are sometimes published several years later following the data collection period. The GTAP version 9 data base documentation also mentions that even though sometimes it is not possible to have the latest data, the I-O coefficients are generally changing relatively slower and the data are updated to reflect various macroeconomic, trade, and energy targets.

As mentioned by Avetisyan and Hertel (2020), the study omitted the validation of maritime transport use in the modified GTAP model, due to the lack of available historical data on international maritime transport use. However, the estimated results for maritime transportation are likely to be robust, because the modal substitution elasticities were estimated for land-air and land-water transport pairs for 229 exporter countries worldwide and then these pairwise elasticities of substitution were combined using the weighted transport cost shares from the GTAP version data base to generate the air-water-other modal substitution elasticities by commodity, source and destination for using in the GTAP model. The authors demonstrate that in most regions the GTAP simulation based and historical series for air and other transport show strong agreement, and therefore it is very likely that the estimated results for maritime transportation that are based on the same aggregated air-water-other modal substitution elasticities are also consistent and robust.

6.5 Summary of assessment justification

This chapter and the preceding chapter have considered a range of potential modelling approaches for assessing impacts on states. They are evaluated for their relative transparency, accuracy, complexity, cost, data requirements and policy relevance. This identified that a SCGE modelling approach was the most suited overall, and a specific version of SCGE has been developed for the purpose of modelling GHG mitigation policy related impacts on indicators relevant to the IMO’s criteria. A discussion of the chosen modelling approach’s validation is undertaken. The options for addressing disproportionate negative impacts are compared and reviewed in this Chapter and the option identified (revenue redistribution) can be incorporated for estimation with the same modelling framework that is used to assess negative impacts.

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27 https://www.gtap.agecon.purdue.edu/resources/download/7642.pdf

7 Assessment of impacts on states

Chapter 5 and 6 have both identified and justified a computational method for producing quantitative estimates of the impacts on states of a mid-long term policy option. These Tasks have also identified some of the shortcomings of this approach relative to the IMO's criteria for assessing impacts, and the data coverage of different countries.

This Task therefore undertakes an assessment of impacts on states in two different ways:

a. The computational approach is applied to all countries, but with different levels of aggregation (e.g. some countries are grouped into regions). The impacts that this creates are examined at a global level, as well as at the level of groupings of countries to understand the indicative trends.
b. The computational approach is complemented by case studies which in some cases use more granular results for individual countries, and in other cases considers wider evidence to understand the potential impacts

The subsequent sections describe first the computational analysis and its results, and then the case studies assessments.

7.1 Assessment of impacts using a computational approach - GTAP modelling

Chapter 4 identified that GTAP was a justified modelling framework to undertake investigation into impacts. To apply that model to the specific assessment of impacts associated with the candidate policy options described in Task 1 and 2 requires preparation of specific inputs and assumptions which are justified here.

7.1.1 Specifying assumptions on carbon intensities of shipping

In the GTAP model it is impossible to distinguish between domestic and international transport emissions. Therefore, calculating international emission intensities per dollar of transport services output (economic emission intensities) directly from the GTAP emissions data will result in inaccurate estimates, since these economic emission intensities will include both sources of transportation emissions. Additionally, the lack of domestic transport margins in the GTAP model makes it even more difficult to differentiate between domestic and international transport emissions.

In this project we develop a methodology to separate the domestic and international elements of transport emissions. We then calculate the economic emission intensities of international maritime transportation for each region pair, enabling more accurate estimation of changes in transport costs for each route driven by the long-term emission abatement measures for international maritime transportation.
More specifically, we develop the following steps involved in a comprehensive assessment of economic emission intensities of international maritime transportation in the GTAP model:

1. Use the value of transport services output by region and the value of exports of water transport services by source and destination region to compute the share of exported maritime transport services by route in the total maritime transport services output.
2. Apply the share of exported maritime transport services to maritime transport emissions generated in each region, and then divide it by the cost of maritime transport to ship goods from the source to destination region.

This methodology enables more accurate estimation of economic emissions intensities of maritime transport by source and destination. It should be noted that due to the GTAP database limitations (availability of transport emissions for each good shipped from a source to destination region) we are not able to generate the maritime transport economic emission intensities by *commodity*, source and destination.

7.1.2 Converting fuel cost increases and market-based measures to changes in transport cost

Decarbonization of maritime transport requires a switch from fossil fuels (HFO, MGO and LNG) to renewable fuels (biofuels and e-fuels generated with renewable electricity). The renewable fuels are more expensive than fossil fuels and their use will therefore result in an increase in maritime transport costs. In addition, some of the mid- or long-term measures selected involve raising revenue e.g. taxation). All of these measures can be converted to increased transportation costs (which can be modelled as a transport tax) for any good shipped from source to destination by water, air or land transport. Therefore, we study the impact of tax regulatory measures on the use of international transport services, emissions, trade and other macroeconomic variables for all countries by perturbing maritime transport costs in the modified GTAP-E model.

More specifically, we analyze the effect of a maritime emissions tax by representing such a tax in terms of the *ad valorem* impact on the shipping cost of traded merchandise. Although the emissions tax ($/t$CO_2$) is the same for all traded goods shipped by maritime transport, the economic emissions intensities (tCO_2/$, maritime transport emissions per dollar of maritime transport services) are trade route specific.

In our analysis we consider low and high carbon dioxide tax scenarios imposed on international maritime transportation, $250/t$CO_2$ and $400/t$CO_2$, respectively. These carbon prices are taken from existing literature (Smith et al. 2019, Faber et al. 2020 respectively) to provide an indicative range of the carbon price that might be needed to achieve substitution of zero-carbon fuels. The literature from which these fuels are obtained assumes zero (or very low) operational/tailpipe emissions as well as zero (or very low) upstream emissions (production, transport, storage). The carbon price is significantly driven by the costs of the fuels (and to a lesser extent the cost of technology and modification to the design of the ship, which in turn is driven by the cost of the feedstocks to the fuels — including renewable electricity). The modelling is carried out as a cross-sectional analysis — to simulate what might happen at a given point in time at which carbon prices are of magnitudes that incentivize mass market use of zero-carbon fuels. In practice, there may be an initial period with lower carbon prices resulting in incentives for smaller volumes of the fleet using zero-carbon fuels. In order to assess impacts, it is the higher carbon prices that are tested here.

Carbon prices are applied to the economic model GTAP under the assumption that the revenues generated are reinvested into shipping's decarbonization, and that the point under which economic impact analysis is being undertaken corresponds to the mid-point of the fleet's decarbonization. E.g. a state when approximately 50% of the fleet (by energy share) has adopted zero-carbon fuels, and the remaining 50% of the fleet is still using fossil fuel. This is to ensure the modelling is feasible. In practice decarbonization will happen over time and with a gradual change in fuel mix. The modelling only represents a cross-sectional analysis, at one point during the transition, and an approximate 'mid point' is chosen, a point at which:

- approximately half of the fleet is using zero-carbon fuel (and is therefore not paying a carbon price, but does use a higher cost of fuel albeit with some portion of that increased cost reduced through subsidy provided by carbon price revenue.
- The remainder of the fleet is still using fossil fuel, but paying in addition a carbon price

That state is therefore modelled as an effective carbon price (experienced as an average across a trade route) which is 50% of the input carbon tax levels (of $250/t$CO_2$ and $400/t$CO_2$). In earlier points in the transition, the carbon price could be lower, as the volumes of fuel subsidy would be lower. At later points in the transition, the carbon price may on the one hand be higher (tending towards the cost difference to zero-carbon fuel), but on the other hand be reduced as costs to produce zero-carbon fuels benefit from economies of scale, technology and production advancements, etc. This midpoint, which uses current (2020) estimates of the cost of zero-carbon fuel therefore represents a conservative assumption and potential high point in the carbon price. However, it should be noted that how carbon prices are set and what this implies to the timing of different revenue magnitudes and impacts is a question of detailed policy design that this modelling assumption is not intended to preconceive. For example, it may be preferred to front load collection of revenue by setting a carbon price higher than necessary for the mitigation objective, in order to increase the optionality for addressing disproportionately negative impacts on states. Alternatively, it may be preferred to minimize the earlier carbon price, in order to minimize the magnitude of any impacts on states that are created.

To understand the direct and indirect impacts of these two tax scenarios, we convert the emission taxes to increased maritime transport costs for each trading country pair using the following expression:

$$ptrans_{m,i,r,s} = 100\% * ECEMINTENS_{m,r,s} * CO2TAX \qquad (1)$$

where:

$ptrans_{m,i,r,s}$ is the percent change in the price of international transport mode *m* to ship good *i* from region *r* to *s*;
$ECEMINTENS_{m,r,s}$ is the economic emission intensity of transport mode *m* by source *r* and destination *s* region (tCO_2/\$);
CO_2TAX in the carbon tax imposed on transport services (\$/tCO_2).

The list of maritime emissions reduction measures includes the following:

1. Low price of CO_2 abatement - \$250/tCO_2.
2. High price of CO_2 abatement - \$400/tCO_2.

All of these measures are represented in terms of increased sea transport costs for any good transported along any route, and we use this as basis for defining our list of scenarios that are simulated using our modified version of the GTAP-E model. Based on the results some useful insights are proposed on mitigating the negative disproportional impacts on some countries in the model.

Since in our model we have 51 regions, there will be 2,601 bilateral country routes that will be affected by increased maritime transport costs due to the carbon taxation policy. The following table shows an example of converting the maritime transport emission tax to *ad valorem equivalents* of increased water transportation costs for all goods shipped from the European Union to the world regions. Due to variations in economic emission intensities of maritime transport shipping across regions, the *ad valorem* impact on the shipping costs is different for each shipping route. This can sometimes be counter-intuitive because seemingly similar trade routes have very different emissions intensities. For example EU-China emits only 0.07 $kgCO_2$/\$ of transport services (e.g. because of economies of scale), whereas EU-rest of South and East Asia, a similar distance apart, has an emissions intensity of 2.8 $kgCO_2$/\$ of transport services.

Table 16 - Ad valorem equivalents of \$250/tCO_2 and \$400/tCO_2 emissions abatement prices on water transport for the EU exports

From the European Union to Regions	Economic emissions intensity (kgCO_2/ \$transport)	Emission price \$250/tCO_2		Emission price \$400/tCO_2	
		Emissions tax per \$ of transport services (\$tax/ \$transport)	Change in transport costs (%)	Emissions tax per \$ of transport services (\$tax/ \$transport)	Change in transport costs (%)
United States	0.038	0.005	0.47	0.008	0.75
Canada	0.323	0.040	4.04	0.065	6.46
European Union	1.357	0.170	16.96	0.271	27.13
Japan	1.253	0.157	15.66	0.251	25.06
China, Hong Kong	0.068	0.008	0.84	0.014	1.35
Brazil	0.727	0.091	9.08	0.145	14.53
India	0.735	0.092	9.19	0.147	14.71
Russia	0.199	0.025	2.49	0.040	3.98
Oceania countries	0.844	0.106	10.55	0.169	16.89
Dominican Republic	0.015	0.002	0.19	0.003	0.30
Puerto Rico	0.035	0.004	0.43	0.007	0.69
Trinidad and Tobago	1.493	0.187	18.66	0.299	29.86
Cambodia	0.120	0.015	1.50	0.024	2.40
Lao People's Dem. Republic	0.076	0.009	0.95	0.015	1.51
Malaysia and Indonesia	0.510	0.064	6.37	0.102	10.19
Afghanistan, Bhutan, Maldives	0.144	0.018	1.80	0.029	2.88
Bahrain	0.015	0.002	0.19	0.003	0.30
Benin	0.011	0.001	0.14	0.002	0.23
Burkina Faso	0.009	0.001	0.11	0.002	0.18
Guinea	2.356	0.294	29.45	0.471	47.11
Togo	0.013	0.002	0.16	0.003	0.26
Rwanda	0.283	0.035	3.54	0.057	5.66
Bangladesh	0.012	0.001	0.15	0.002	0.24
Madagascar	0.060	0.007	0.74	0.012	1.19
Malawi	0.866	0.108	10.83	0.173	17.33
Senegal	0.006	0.001	0.08	0.001	0.12
Tanzania	0.024	0.003	0.31	0.005	0.49
Zimbabwe	0.265	0.033	3.32	0.053	5.31
Rest of Europe and F. S. Union	0.767	0.096	9.59	0.153	15.35
Rest of East and South East Asia	2.781	0.348	34.76	0.556	55.62
Rest of South Asia	0.926	0.116	11.58	0.185	18.53
Rest of Oceania	0.377	0.047	4.72	0.075	7.55
Rest of Caribbean	0.277	0.035	3.46	0.055	5.54
Central and Caribbean Americas	0.079	0.010	0.99	0.016	1.58
South and Other Americas	0.758	0.095	9.47	0.152	15.16
Central Africa	0.049	0.006	0.62	0.010	0.99
Rest of Eastern Africa	0.068	0.009	0.85	0.014	1.36
Rest of Western Africa	0.018	0.002	0.22	0.004	0.35
Sub Saharan Africa	0.192	0.024	2.41	0.038	3.85
Middle Eastern and North Africa	0.190	0.024	2.38	0.038	3.80
Rest of the World	0.248	0.031	3.10	0.050	4.97

7.1.3 Presentation of results

Tables 17-18 illustrate the results of low and high price of CO_2 abatement - $250/t$CO_2$ and $ 400/tCO_2 scenarios.

Table 17 - Results of the low price CO_2 abatement with $250/t$CO_2$ (effective carbon price $125/t$CO_2$) emission price

Regions	GDP, % change	Investment, % change	Exports, % change	Imports, % change	Emissions, % change	Land Transport, % change	Water Transport, % change	Air Transport, % change
United States	0.002	0.276	-0.127	0.313	0.037	0.106	0.171	0.253
Canada	-0.004	0.014	-0.181	-0.276	0.077	0.812	0.594	0.041
European Union	-0.022	-0.420	-0.159	-0.637	-0.038	0.968	0.822	0.367
Japan	0.001	0.155	-0.181	-0.028	0.010	0.017	0.738	0.462
China, Hong Kong	0.001	0.069	-0.131	-0.039	0.021	0.140	0.313	0.417
Brazil	0.001	0.161	-0.288	-0.048	-0.012	0.011	0.178	0.060
India	0.010	0.080	0.012	0.113	0.021	0.012	0.622	-0.017
Russia	0.005	0.222	-0.066	0.201	0.000	0.275	0.116	0.179
Oceania countries	-0.001	0.100	-0.163	-0.100	-0.009	0.063	0.156	-0.051
Dominican Republic	-0.020	0.008	-0.133	-0.357	-0.141	0.219	0.581	0.242
Jamaica	-0.278	-2.237	-0.575	-2.690	-0.799	1.259	1.108	1.484
Puerto Rico	0.000	0.229	0.043	0.287	0.050	0.152	0.628	0.414
Trinidad and Tobago	-0.014	-0.134	-0.128	-0.383	-0.060	0.054	0.230	0.089
Cambodia	-0.121	0.031	-0.165	-0.967	-0.879	0.286	0.381	0.519
Lao People's Dem. Republic	0.008	0.342	-0.087	0.257	-0.010	0.094	0.233	0.246
Malaysia and Indonesia	-0.004	0.087	-0.111	-0.081	0.003	0.012	0.166	0.151
Singapore	-0.039	-1.460	-0.344	-1.170	0.361	5.394	0.972	1.584
Afghanistan, Bhutan, Maldives	-0.002	0.127	-0.156	-0.024	-0.091	0.302	0.635	0.255
Bahrain	0.002	0.237	-0.065	0.051	0.104	1.070	0.667	0.517
Benin	3.699	19.867	-23.515	10.087	7.953	4.669	3.604	4.013
Burkina Faso	0.046	0.636	0.070	0.703	0.099	-0.010	0.016	-0.145
Guinea	-0.434	-0.792	-2.457	-2.409	-0.788	-0.223	-0.609	-0.403
Togo	-2.013	-18.217	7.239	-7.208	-4.546	-3.017	1.143	1.193
Mauritius	-0.048	-0.824	-0.418	-1.304	-0.319	0.479	0.553	-0.284
Mozambique	0.643	-13.632	-12.667	-35.169	-12.289	-6.900	-11.665	-7.642
Rwanda	-0.134	-0.211	-1.097	-1.189	-2.064	0.253	-0.289	0.091
Uganda	0.050	-3.635	-6.058	-15.098	-0.876	-1.728	-1.073	-0.908
Zambia	-0.225	-26.819	-12.070	-44.494	-11.153	-4.981	-7.694	-3.593
Ethiopia	-0.021	-0.055	-0.615	-0.496	0.059	0.095	0.102	-0.266
Nepal	-0.008	-0.025	-0.385	-0.333	-0.042	0.021	0.130	-0.017
Bangladesh	0.001	0.108	-0.076	0.011	0.005	-0.002	0.011	0.069
Madagascar	-0.002	0.211	-0.006	0.152	-0.044	0.028	0.354	0.085
Malawi	-0.226	-9.791	1.515	-3.524	-1.985	-0.923	-1.381	3.222
Senegal	0.000	0.148	0.012	0.022	0.065	0.574	0.095	-0.049
Tanzania	-7.275	-17.119	-14.647	-37.495	-8.563	20.611	0.782	5.057
Zimbabwe	-5.552	-4.935	-36.561	-45.644	-10.507	4.455	15.052	20.711
Other E. Europe and Rest of F.S.U.	0.014	0.187	0.018	0.201	0.015	0.780	0.247	0.124
Rest of European Countries	-0.033	-0.427	-0.391	-1.110	-0.415	0.479	0.670	-0.260
East Asia	-0.020	-0.236	-0.112	-0.395	0.033	1.910	0.910	1.039
Rest of South East Asia	-0.031	-0.501	-0.043	-0.541	-0.070	0.404	0.391	0.522
Rest of South Asia	-0.032	-0.360	-0.488	-1.110	-0.165	-0.009	1.338	0.728
Rest of Oceania	0.013	0.225	0.088	0.203	0.147	0.159	0.564	1.148

Regions	GDP, % change	Investment, % change	Exports, % change	Imports, % change	Emissions, % change	Land Transport, % change	Water Transport, % change	Air Transport, % change
Rest of Caribbean	-0.020	-0.065	-0.122	-0.254	-0.050	0.449	0.660	0.436
Central and Caribbean Americas	-0.001	-0.005	-0.198	-0.474	-0.034	0.054	0.389	0.267
South and Other Americas	0.002	0.181	-0.107	0.055	-0.014	0.119	0.476	0.268
Central Africa	0.111	0.392	0.849	1.909	0.804	0.119	-0.056	-0.528
Rest of Eastern Africa	-0.001	0.070	-0.011	0.098	0.006	0.038	0.031	0.196
Rest of Western Africa	0.025	0.128	0.008	0.087	0.067	0.336	0.430	0.131
Sub Saharan Africa	0.004	0.269	0.104	0.372	0.197	0.188	0.174	-0.064
Middle Eastern and North Africa	0.000	0.130	-0.049	0.054	0.062	0.476	0.712	0.285
Rest of the World	0.000	0.026	-0.110	-0.167	0.041	0.673	0.675	0.142

Table 18 - Results of the high price CO_2 abatement with \$400/tCO_2 (effective carbon price \$200/tCO_2) emission price

Regions	GDP, % change	Investment, % change	Exports, % change	Imports, % change	Emissions, % change	Land Transport, % change	Water Transport, % change	Air Transport, % change
United States	0.004	0.441	-0.203	0.501	0.059	0.169	0.274	0.405
Canada	-0.006	0.022	-0.289	-0.441	0.123	1.295	0.952	0.065
European Union	-0.035	-0.673	-0.255	-1.020	-0.061	1.545	1.317	0.587
Japan	0.001	0.247	-0.289	-0.046	0.016	0.027	1.183	0.740
China, Hong Kong	0.002	0.110	-0.209	-0.063	0.033	0.224	0.501	0.668
Brazil	0.002	0.258	-0.461	-0.076	-0.018	0.017	0.285	0.096
India	0.016	0.127	0.019	0.180	0.033	0.020	0.997	-0.028
Russia	0.008	0.354	-0.105	0.320	0.000	0.439	0.186	0.287
Oceania countries	-0.001	0.160	-0.261	-0.160	-0.014	0.101	0.249	-0.082
Dominican Republic	-0.032	0.017	-0.210	-0.562	-0.225	0.344	0.927	0.382
Jamaica	-0.444	-3.572	-0.922	-4.298	-1.277	2.009	1.769	2.368
Puerto Rico	0.000	0.366	0.069	0.459	0.081	0.243	1.007	0.663
Trinidad and Tobago	-0.023	-0.215	-0.204	-0.611	-0.096	0.087	0.369	0.142
Cambodia	-0.194	0.050	-0.264	-1.547	-1.406	0.458	0.610	0.831
Lao People's Dem. Republic	0.012	0.544	-0.138	0.411	-0.016	0.150	0.373	0.393
Malaysia and Indonesia	-0.006	0.138	-0.177	-0.130	0.005	0.020	0.265	0.241
Singapore	-0.063	-2.338	-0.551	-1.873	0.576	8.608	1.557	2.534
Afghanistan, Bhutan, Maldives	-0.003	0.202	-0.249	-0.039	-0.144	0.482	1.017	0.408
Bahrain	0.003	0.378	-0.102	0.086	0.166	1.707	1.068	0.826
Benin	5.907	31.726	-37.556	16.110	12.702	7.458	5.757	6.409
Burkina Faso	0.074	1.017	0.113	1.127	0.159	-0.017	0.026	-0.233
Guinea	-0.694	-1.266	-3.930	-3.853	-1.260	-0.358	-0.974	-0.644
Togo	-3.216	-29.101	11.563	-11.513	-7.262	-4.820	1.827	1.911
Mauritius	-0.077	-1.320	-0.669	-2.088	-0.510	0.765	0.885	-0.454
Mozambique	1.015	-21.674	-20.163	-55.937	-19.555	-10.974	-18.578	-12.175
Rwanda	-0.213	-0.340	-1.759	-1.925	-3.289	0.403	-0.458	0.144
Uganda	0.072	-5.770	-9.601	-23.944	-1.395	-2.749	-1.703	-1.442
Zambia	-0.371	-42.383	-19.107	-70.338	-17.654	-7.865	-12.184	-5.692
Ethiopia	-0.034	-0.089	-0.983	-0.792	0.095	0.152	0.163	-0.427
Nepal	-0.013	-0.040	-0.614	-0.533	-0.067	0.032	0.207	-0.028

Regions	GDP, % change	Investment, % change	Exports, % change	Imports, % change	Emissions, % change	Land Transport, % change	Water Transport, % change	Air Transport, % change
Bangladesh	0.002	0.172	-0.120	0.017	0.009	-0.003	0.017	0.110
Madagascar	-0.003	0.335	-0.011	0.241	-0.071	0.044	0.566	0.135
Malawi	-0.362	-15.747	2.439	-5.688	-3.182	-1.465	-2.196	5.145
Senegal	0.000	0.237	0.019	0.035	0.105	0.916	0.152	-0.079
Tanzania	-11.409	-26.843	-22.968	-58.790	-13.388	32.456	1.235	7.932
Zimbabwe	-8.713	-7.747	-57.346	-71.637	-16.446	7.029	23.676	32.530
Other E. Europe and Rest of F.S.U.	0.022	0.298	0.029	0.321	0.024	1.245	0.395	0.199
Rest of European Countries	-0.053	-0.685	-0.627	-1.778	-0.664	0.764	1.074	-0.416
East Asia	-0.033	-0.378	-0.179	-0.632	0.052	3.048	1.458	1.663
Rest of South East Asia	-0.050	-0.802	-0.069	-0.865	-0.112	0.644	0.626	0.835
Rest of South Asia	-0.051	-0.576	-0.780	-1.776	-0.264	-0.015	2.140	1.164
Rest of Oceania	0.021	0.360	0.141	0.326	0.236	0.253	0.903	1.837
Rest of Caribbean	-0.032	-0.105	-0.195	-0.408	-0.081	0.716	1.058	0.697
Central and Caribbean Americas	-0.002	-0.008	-0.315	-0.757	-0.053	0.087	0.623	0.426
South and Other Americas	0.003	0.289	-0.170	0.087	-0.022	0.189	0.763	0.429
Central Africa	0.175	0.619	1.338	3.010	1.269	0.193	-0.078	-0.832
Rest of Eastern Africa	-0.001	0.111	-0.018	0.154	0.010	0.060	0.050	0.312
Rest of Western Africa	0.042	0.209	0.013	0.141	0.109	0.536	0.688	0.210
Sub Saharan Africa	0.006	0.426	0.162	0.586	0.310	0.299	0.278	-0.101
Middle Eastern and North Africa	0.000	0.207	-0.078	0.086	0.098	0.759	1.142	0.456
Rest of the World	0.000	0.041	-0.177	-0.268	0.066	1.074	1.082	0.226

7.1.4 Discussion of quantitative results at global and regionally grouped level

General findings and global impacts, mitigation only (no impacts addressed)

As might be expected given the variability and complexity of interactions between trade and national economies, the quantitative results presented show a significant range of impacts. There is no consistent or generalizable behavior for all economies. Some benefit (net positive impacts) from the application of decarbonization policy that increases transport costs, and some experience net negative impacts. As an aggregate (e.g. in combination across all the economies studied) there is only a limited (e.g. small) impact.

The results are the product of the interactions between carbon intensity of different transport modes and the potential for substitution, the relative balance between imports and exports (and the respective trading partners for these), along with the consequent impacts on investment. For example, in the European Union GDP is reduced by -0.022%. This is mainly driven by reduced exports and consumption. Specifically, we observe reduction in the exports of mostly coal and natural gas and decline in the consumption of oil, oil products, and energy intensive industry goods. Brazil shows increase in GDP by 0.001%, which is a result of increased investment. There are several interactions occurring within the Brazilian economy which can help understand how this result comes about, and are discussed in Section 7.2.3. The GDP in Benin grows by 3.699%, mainly due to increased private consumption and investment. We observe growth in the consumption of non-tradable services, goods produced by energy intensive industries, and other industrial services.

The consequence of a higher carbon price is a proportionate increase in impacts. This can be found from comparing Table 17 (effective carbon price of $125/tCO_2$) and Table 18 (effective carbon price of $200/tCO_2$). In Table 18, the GDP change is approximately 160% of the values of Table 17.

High income economy impacts

Three high income economies and the EU have disaggregated results – United States, Canada, Japan. For all scenarios, United States and Japan see increases in GDP and Canada and EU reductions. All see similar reductions in exports (0.1 to 0.2% reduction in exports by value, for an effective carbon price of $125/tCO_2$). The explanation for the variation of net impact on GDP comes from the different consequences on investment – with the EU having the most significant negative impact on investment due to the increase in transport cost. The consequence of a generalised increase in transport costs depends on the country or region's circumstances. For nearby trading partners, the generalised increase in transport cost can result in substitution occurring and an increase in market share relative to more remote trading partners. The transport cost increase can also cause imports to be substituted with domestic production – therefore increasing investment in the country or region. Several of these dynamics are discussed in Section 7.2.2 and 7.2.3 by looking deeper at two specific case studies.

Middle income and emerging economy impacts

Several of the diversified and larger economies are shown in the results to increase their GDP as a function of the policy scenarios simulated. For example, all of China, Brazil, India and Russia have net positive economic impacts at both levels of carbon price. The impacts that occur on flows of imports and exports are generally counterbalanced by increased investment and domestic consumption. This is explained by the strength of these economies across multiple sectors so that whilst there might be negative impacts on some sectors of the economy, these become substituted by other sectors of the economy, with consequent upsides in investment and domestic consumption terms.

South America besides Brazil does not have the disaggregation in data to be able to identify whether there are countries with net positive or net negative results. However, overall as an aggregate the region has a net positive impact from the scenarios. A small reduction in exports is offset by an increase in investment.

Two other countries that have disaggregated results are Malaysia and Indonesia, albeit in aggregation across their two economies. In combination for these two countries there is a moderate net negative impact (-0.004%) estimated as a consequence of the application of a carbon price. This potential for net negative impacts is also observed for some of the regional aggregations of economies, South Asia and South East Asia both experience net negative impacts of -0.03% GDP at the lower level of carbon price, rising to -0.05% at the higher level of carbon price. This indicates that the finding that many middle income and emerging economies do not have net impacts is not a generalizable rule and that analysis is desirable on all individual countries to understand the range of impacts experienced and whether these may be defined as disproportionate.

Where they occur, these findings of net positive impacts are despite the comparative distance of some of these economies from their main export markets and therefore associated relative high economic emissions intensity ($kgCO_2$/\$transport) (Table 1).

SIDS and LDC impacts

Generally, the data for SIDS and LDCs has poor coverage. Only five SIDS are included at national level: Jamaica, Trinidad and Tobago, Dominican Republic, Mauritius and Singapore. All five have net negative impacts with reductions in GDP ranging between -0.014% and -0.28% under the $250/tCO_2$ carbon price. This GDP reduction is associated with reductions in exports and imports which are also accompanied by reduced investment in some but not all cases. The impacts on aggregations of countries representing SIDS e.g. 'rest of Caribbean' are similarly net negative.

Pacific SIDS are aggregated within the 'rest of Oceania' group. Surprisingly, these show a net positive impact, including from both increased investment as well as increased imports and exports (by value). Given the small size of these economies, this is likely to be indicative of the poor quality of the input data describing these economies rather than a genuine result.

The remaining Atlantic, Indian Ocean and South China Sea SIDS are not included as groups and given the small size of their economies within the groups in which they are aggregated are hard to draw impacts on from the results. The depth of analysis is also restricted by the quality of data available for many of these economies. Without good trade statistics as well as information on the statistics of different sectors of the economy, representation within a CGE model is difficult. For the purposes of both assessing and addressing any identified disproportionate negative impacts, a higher quality of measurement is required. However, even without a minimum quality of data for CGE modelling, some inference can be drawn from the fact that those SIDS that have been analysed have universally been net negatively impacted, and it could be expected that given maritime transport dependency of SIDS, they would all experience similar impacts.

The results for LDCs are particularly variable and include the highest net negative and positive impacts, and largest magnitudes of change in investment, imports and exports. Some of this variability could be genuine and some could be an artifice of the low quality of the data and its knock on consequences to the quality of the modelling. Of the LDCs that are disaggregated in the analysis, approximately twice as many have net negative impacts than those that have net positive impacts. This implies that in common with SIDS and in contrast to the middle-income economies studied, LDCs are less able to counterbalance the consequences on the sectors of their economy negatively impacted by an increase in transport cost, with other sectors of their economy.

Addressing impacts

In this section we use the modelling to produce an estimate of the scale of cost for addressing some of the impacts. The estimate of how to address impacts, and the consequence of addressing impacts, is made difficult by the lack of a definition of what constitutes a disproportionate negative impact, as well as by the lack of availability of disaggregated data within the results. However, the results produced can still be used to provide some insight.

Of the 26 SIDS and LDCs that were individually assessed, 20 experienced net-negative impacts (ranging from -0.002% to -7.3% at the lower carbon price). On the 2011 figures that GTAP is based on, an upper bound for addressing these net negative impacts can be found if they are fully addressed. In other words, the inclusion of some form of value transfer equivalent to the GDP reduction is included in the design of the policy measure and it is assumed that the value transfer is perfectly absorbed into the economy in order to cancel out the negative impact. This concept is just one of many candidate ideas for addressing disproportionate negative impacts – and for one specific group of countries at a specific level of full compensation. The example does not preclude the many alternative ideas (as discussed in Chapter 6) or groups of countries could be applied, and this would create different implications for the levels of revenue needed. For the year 2011, noting the many sources of uncertainty in the data and modelling, the total negative economic impact across those 20 economies totals $2.7bn. When considered as a price on carbon for the approximately 305Mt of CO_2 (midpoint of decarbonisation) that is represented in GTAP, this upper bound would correspnd to $8.8bn at the lower carbon price or approximately %7 of the cost of mitigation. There are 46 LDCs and 38 SIDS, but eight countries overlap between these lists, so the total is 76. The sample examined in this study therefore represents approximately a third of the total number of SIDS and LDCs. However, because the cost of addressing impacts in economies is related to the size of the economies, and the remaining SIDS and LDC economies are not significantly larger than this sample, overall for SIDS and LDCs, the magnitudes of cost for addressing SIDS and LDC impacts can be considered indicative if multiplied by three, bearing in mind the sources of uncertainties both in the underlying modelling and this extrapolation.

For middle income and emerging economies, on the one hand the size of economies increases (relative to SIDS and LDCs), but on the other hand the impacts experienced, at least for the sample of economies studied here, reduces. Most of the individual middle income and emerging economies studied saw net positive impacts, which if accurate would imply that the economic impacts are unlikely in need of being addressed.
The combination of Malaysia and Indonesia were the only disaggregated example of net negative impacts, and in combination the net negative GDP magnitude was $0.4bn (on the lower carbon price), in spite of the much larger combined GDP of these two economies than the SIDS and LDCs. However, there are a number of aggregated emerging and middle-income economies that did in aggregate experience negative impacts e.g. Asia, Central America. Therefore, when looked at as individual economies it is likely there will also be negative impacts experienced due to the application of CO_2 mitigation policy on international shipping. Although the impacts might be different between countries. It therefore remains possible that whilst not all of the impacts may be negative and disproportionate, some of these will be disproportionately negative impacts, and if in combination there is a net disproportionately negative impact, addressing these impacts will be important. Until a full disaggregated analysis has been produced, it is impossible to estimate the bounds of the costs to address those impacts.

Uncertainties of these impacts and their implications to interpretation of results

The version of GTAP used in this analysis is for the year 2011. In that year GTAP data are inclusive of 610Mt of shipping CO_2 emissions (domestic and international). The Third IMO GHG Study estimated total shipping emissions of 1,022Mt and international shipping emissions of 850Mt respectively. This indicates that whilst the majority of shipping emissions are represented, there are significant portions of global shipping activity which do not appear to be included in this version of the model, or the economic activity of shipping is included at a carbon intensity lower than the IMO Study estimated.

The analysis undertaken uses a static model based in 2011. Since 2011, the underlying strength and diversity of economies, as well as the role of transport services in economies has evolved. Furthermore, the application — to understand the impacts of a future implementation of GHG policy — is for some point in the future, when further changes will have taken place. This can include improvements in efficiency and reduction in carbon intensity which will reduce the scale of impacts experienced due to a price on carbon emissions, as well as how measures may be applied and changes may occur in competing modes of transport. Therefore these results are useful for understanding indicative impacts including on different types of economy, but cannot be expected to produce results which are accurate in their absolute values for a future implementation.

Economic modelling in GTAP is dependent on the quality of data describing different sectors of the economy, as well as how they interact domestically and internationally. For many countries, in particular SIDS and LDCs, the data may be of poor quality and the results of high sensitivity to that quality. On the other hand the data for larger countries is likely to be higher quality both due to better data availability and the higher sensitivity of the model's general results to these inputs (therefore their higher attention in validation processes). This data quality issue may explain some of the results in the list of SIDS and LDCs that are studied in detail which include countries that have both the most extreme positive and negative impacts. However, without a detailed investigation and validation process at the level of individual economies, it is not possible at this point to attribute results to genuine features of an economy. This further implies that interpretation of the results should be as indicative results for types of economy and not absolute magnitudes for individual economies.

7.2 Case study investigation of impacts on states

7.2.1 Pacific

Including because of the anticipated poor quality of data and resolution in GTAP, this section undertakes a more detailed exploration of the potential impacts of GHG mitigation measures for SIDS located in the Pacific as well as how they might be addressed. As noted previously, detailed modelling of these impacts is precluded by the partial coverage and uncertain quality of relevant input data, in particular concerning the domestic maritime sectors and wider macro-economies of Pacific SIDS. The conclusions set out below should therefore be regarded as tentative and preliminary, but nonetheless illustrative of how negative impacts for Pacific SIDS of regulatory measures for international shipping could be readily offset and would likely deliver considerable benefits for the countries concerned. The key conclusions of this case examination are as follows:

Impact type	Summary description of impacts and offset opportunities
Transport costs	Transport costs for Pacific SIDS are among the highest in the world, with high costs attributable to a combination of small-scale markets, old infrastructure, extreme distances, and dependency on imported fossil fuels. The short-term sensitivity of these costs to international GHG regulation is unclear, and would likely be offset by investment in operational efficiency (e.g. newer ships and other transport infrastructure).
International trade value by modes of transport	Not relevant to the case of Pacific SIDS which are entirely reliant on maritime transport for international trade in goods
Outputs of economic sectors	The very high dependence of domestic transport and connectivity on imported fossil fuels is one of the major acknowledged constraints on social and economic development in Pacific SIDS. Increasing availability of lower cost and lower carbon transportation options and technology, driven by international regulation, represents a significant long-term positive impact in this context. Emissions reductions and innovation driven by regulation of international shipping will likely reinforce these positive impacts.
GDP	The short-term GDP impacts of international GHG regulation for shipping are unclear. Agricultural exports are a significant but declining share of the economy of larger Pacific SIDS (e.g. Fiji) and a marginal contributor to smaller states (e.g. Kiribati). Adverse economic impacts (if any) arising from decline is cost competitiveness from increase in transport costs could be readily offset by reinvestment of revenue form international market-based measures, given the very small scale of the relevant economies.

The following paragraphs provide more details regarding these conclusions and the context they relate to.

Types of impact on Pacific SIDS caused by implementation of GHG mitigation policy on international transport

The critical importance of sea transport to Pacific SIDS and its interrelationship to all levels of socio-economic development are widely recognised and documented.[28] The sector currently has a range of challenges including the prevalence of old, inefficient and undermaintained vessels, and a lack of supporting modern infrastructure including

[28] See: Nuttall et al, *Frontiers in Marine Science*, https://doi.org/10.3389/fmars.2014.00020.

ports, facilities for bunkering, ship building, maintenance, and repair. Existing vessels service and underpin micro-economies at the end of long and narrow operating routes, with the consequence that sea transport within and between Pacific SIDS is the most expensive per unit distance and per capita in the world (see below). Transportation and mobility is a cross-cutting issue central to the sustainable development of Pacific SIDS.[29] These challenges have several urgent and large-scale implications:

Dependency on imported fossil fuels — Pacific SIDS are generally precariously dependent on imported fossil fuels raising critical issues of fuel price vulnerability and security of supply.[30] The Pacific is the most dependent region in the world on imported fuels at 95% dependency, or 99% if Papua New Guinea and Fiji are excluded.[31] Imported petroleum products account for an average of ~40% of GDP in Pacific SIDS, with the transport sector often the largest user of fuel.[32] Although disaggregated data is limited, estimates of the share attributable to sea-transport as a subsector range from 22% in Fiji to 90% in Tokelau. Increased transport costs on international supply chains will cascade through this already-expensive source of energy in these economies.

Negative impacts and risks for the local and global environment — The transport sector's reliance on fossil fuels increases the risk of environmentally damaging spills, and ecosystem damage associated with fuel transport, storage and vessel-source pollution.[33] Pacific Small Island States leaders have called for an end to all fossil fuel subsidies.[34] Leaders have also called for use of higher quality fossil fuels that are less damaging to the environment than those currently in use.[35]

Social, livelihood and employment implications — The lack of regular connectivity amongst many islands in the Pacific is considered one of the binding constraints to both domestic social and economic development and international trade.[36] In the 2015 Hiri Declaration on Strengthening Connections to Enhance Pacific Regionalism, the importance of people-to-people relations, improved institutional governance and enhanced physical connectivity in the Pacific were underscored. It notes that a key component of better connectivity will be improved shipping, which remains the most important mode of transport and trade for Pacific SIDS.[37] The increased cost of imported energy, works counter to that objective.

Climate change commitments and risks — Climate change compounds the above challenges. It creates risks of a greater number of disasters and more pressure on disaster response systems (which are particularly dependent on shipping), this also creates the urgent need to adapt fleets and maritime infrastructure to strengthen their resilience to changes (severe weather, sea-level rise), and is a driver of the need to reduce GHG emissions from sea. Climate change is an urgent threat to the maritime transport sector (and sustainable development generally) in Pacific SIDS, which can be addressed in part through accelerated efforts to decarbonise and adapt the sector in accordance with the 2015 Paris Agreement on Climate Change,[38] and 2030 Agenda for Sustainable Development, supported by the Talanoa Dialogue and other regional and global platforms.

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29 See: UN SIDS SAMOA Pathway (2014) paras 66-67, http://prdrse4all.spc.int/sites/default/files/samoa-pathway.pdf
30 See: Woodruff, A. (2007). The Potential for Renewable Energy to Promote Sustainable Development in Pacific Island Countries, SOPAC.
31 See: AusAID. (2008). '08 Pacific Economic Survey: Connecting the Region. Canberra, ACT: Pacific Affairs Group.
32 See: Nuttall et al, *Frontiers in Marine Science*, https://doi.org/10.3389/fmars.2014.00020.
33 See e.g.: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5274615/
34 Tuvalu Declaration on Climate Change for the Survival of Pacific Small Island Developing States, 12 August 2019.
35 See: Communiqué of the Third Pacific Regional Energy and Transport Ministers' Meeting, Nuku'alofa, Tonga, 26–28 April 2017, para. 18; and https://www.forumsec.org/wp-content/uploads/2019/08/50th-Pacific-Islands-Forum-Communique.pdf
36 See: Holland et al, Carbon Management (2014): https://www.tandfonline.com/doi/pdf/10.4155/cmt.13.78
37 See: https://www.unescap.org/commission/73/document/E73_4E.pdf
38 See: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement.

Direct transport costs — Data on freight rates in Pacific SIDS are limited, however current evidence indicates that transport costs are relatively high, including when compared to other low and middle income countries. UNCTAD estimates that in 2013, the average freight cost as a share of imports was close to 7% for 'developed' economies, 10% for 'developing' economies, and 13% for SIDS in general.[39] Given the geographic remoteness of most Pacific SIDS, transport costs are likely to be higher than for SIDS in general. Any further increase in transport cost due to policy that mitigates international shipping emissions will therefore add to a disadvantaged starting position for both imported goods and cost of living, as well as exported goods.

Food security — The consequence of increased transport costs for the significant share of imported food consumed in the region, as well as for increased costs of domestic and regional transport due to increased energy prices (imported transport energy), is an expected increase in food prices and reduction in food security. On the other hand, higher import prices can stimulate domestic food production.

Disaster response — Most Pacific SIDS are highly vulnerable to disasters which are intensifying due to climate change. Low lying and remote communities are regularly subject to intense storms. To mitigate the loss of life, these events require immediate relief efforts which can normally only be provided through international transport and shipping (e.g. larger ships capable of transporting significant quantities of freight and supplies from nearby hubs). Capacity for disaster response is therefore dependent on the volume of ships in region. If the consequence of mitigation of international shipping emissions is an increase in cost which creates a reduction in demand for shipping, the number and frequency of shipping services in the region may be reduced. The consequence is then less availability of ships for disaster response and less resilience to these events.

Pacific opportunities to address negative impacts, including through modernization of domestic and intra-regional shipping

Global shipping operators are largely absent from Pacific SIDS trade, which is not located on major East-West routes across the Pacific and is predominantly connected to global markets through the relay ports of Singapore, Hong Kong and Busan.[40]

A lack of detailed and updated information concerning the maritime sector in Pacific SIDS — in particular concerning smaller scale domestic and intra-regional shipping — has been consistently identified as a barrier for effective decision-making, and as an ongoing challenge for planning of the sector's development. Current evidence available in various national government datasets is summarised below:

Number and types of vessels — approximately 1,100 vessels larger than fifteen metres operate in Pacific SIDS for which primary data is available. An uncertain but larger number of smaller vessels (< fifteen metres), powered mainly by outboard motors, service shorter routes between the many islands and atolls (n> 1,000) in Pacific Island Countries. The two figures below provide a general overview of fleet composition in current a selection of Pacific Island Countries:

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[39] See: https://unctad.org/system/files/official-document/dtltlb2014d2_en.pdf
[40] See: https://unctad.org/system/files/official-document/dtltlb2014d2_en.pdf

Figure X: Distribution of small (< 15m) and large (> 15m) vessels in PBSP member countries

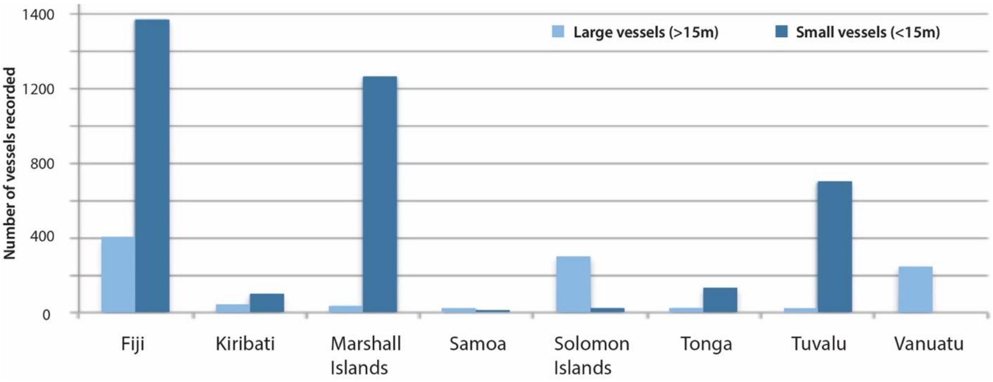
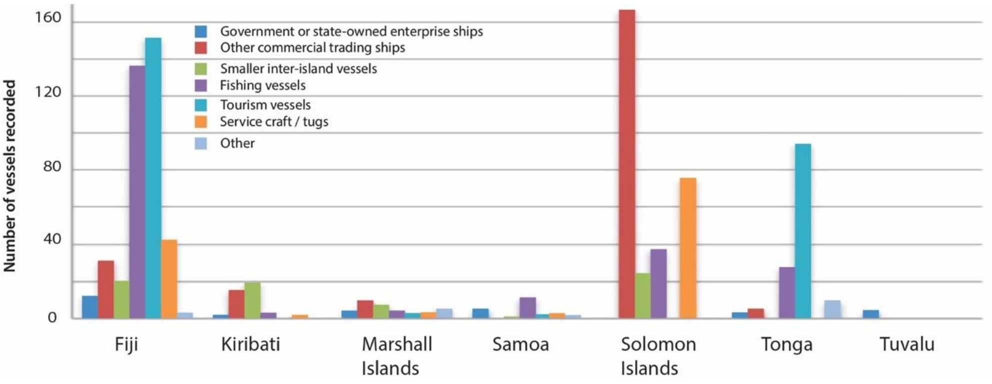


Figure Y: Distribution of vessels in PBSP member countries by type of vessel



Condition of vessels — As noted previously, Pacific SIDS are reliant generally on inefficient, old and under-maintained vessels, with limited supporting infrastructure (e.g. modern ports, bunkering, shipbuilding and repair). Across Kiribati, Fiji, Samoa, Solomon Islands, the Marshall Islands, and Vanuatu, vessels in service have the following age distribution as of 2020: 38% of vessels are more than 30 years old; 21% of vessels are 20–30 years old; 41% of vessels are less than 20 years old.

Given that more than half of all vessels are over 20 years old, the potential is large for replacing vessels with highly efficient vessels that are capable of operating on zero-carbon fuels once those become available in the region. Depending on their characteristics and operating profile, younger current vessels might be suitable for retrofitting with energy efficiency and emissions abatement technologies. Preliminary analysis suggests that by the following roadmap for vessel decarbonisation in PBSP member countries:[41]

By 2030, 40% GHG emissions reduction across fleets of member countries, from targeted deployment of current on-market technology, including upgrades to: propulsion, ship design, main machinery and engine, energy management and recovery, speed/voyage optimisation, trim, just-in-time berthage.

Impacts of GHG mitigation measures

At a political level the near-universal position across Pacific SIDS leadership is that the costs of inaction to secure a rapid transition to low-carbon shipping outweigh any impacts of such action. This political position has manifested in consistent advocacy in relevant international negotiations (e.g. the Marine Environmental Protection Committee of the IMO) for ambitious regulation of international GHG emissions from shipping, and in the development of national/domestic decarbonisation and maritime sector development

[41] See: https://mcst-rmiusp.org/index.php/projects/current-projects/pacific-blue-shipping-partnership.

initiatives such as the Pacific Blue Shipping Partnership (PBSP). Announced in 2019 by the Governments of Fiji and the Marshall Islands, the PBSP is a planned multi-country blended investment program that aims to secure maritime sector upgrading coupled with a 40% reduction of domestic GHG emissions by 2030, with full decarbonisation by 2050 in line with wider regional and global commitments.[42]

Notwithstanding the challenges of limited data and analysis to date, this political and policy position regarding the impacts of GHG regulation of international shipping (and GHG regulation generally) is substantiated by the following potential benefits of progressively decarbonised sea transport to the extent they are driven by international regulation:

- Substantial reductions in operational costs — Current preliminary analyses suggest that retro-fit and purchase of low-carbon passenger and cargo ferries, including locally appropriate combinations of eco-diesel, wind-hybrid, or electric propulsion, could reduce operational energy costs by 20–80%.[43] These substantial savings opportunities are primarily due to the relative old age and poor condition by global standards.
- Macro-economic and fiscal sustainability — reducing need for public expenditure on fuel subsidies, and freeing up private sector resources for investment in more productive activities. Fuel duty concessions and other subsidies in PICs are associated with a range of adverse long-term development outcomes.[44]
- Poverty alleviation and support for local livelihoods — fuel shortages and price volatility have major impacts on local communities across PICs, and on productive sectors such as fisheries which are key contributors to food security and local livelihoods in the region.[45]
- Technology development, local innovation and skills — The sea transport sector connecting Pacific SIDS—with each other and international markets—is currently heavily dependent on imported technology, commodities and skills. A major structural transition of the sector to low- or no-carbon options presents opportunities for the development of nationally appropriate vessels, ports and supporting services, interlinked to regionally-based enterprise, education and training, and underpinned by revitalised pride in the Pacific's seafaring heritage.
- Realising of these benefits is highly dependent on the design of GHG regulations concerning international shipping, with the following implications being particularly relevant.
- GHG regulations that are not revenue generating (e.g. emissions trading excluding Pacific routes) are not desirable because they preclude the possibility of re-investment into local sector transitions, in particular vessel upgrading and replacement which is a precondition of public fiscal and private operational cost savings.
- Revenue generating GHG regulations (e.g. a carbon tax or emission trading inclusive of Pacific routes) would need to divert sufficient resources to Pacific SIDS to offset any short-term adverse impacts on transport costs and economic growth, in accordance with internationally recognised principles such as the Polluter Pays Principle,[46] Common but Differentiated Responsibilities and Respective Capabilities,[47] and 'Leave No-One Behind'[48].
- If focused on larger blue-water vessels, regulation of international shipping GHG emissions are unlikely to have significant short-term cost impacts for domestic

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[42] See: https://www.fiji.gov.fj/Media-Centre/Speeches/PRIME-MINISTER-VOREQE-BAINIMARAMA'S-ADDRESS-AT-THE

[43] Depending on operational context and vessel type. Based on preliminary analysis undertaken by the PBSP Advisory Committee Technical Working Group, available at: https://mcst-rmiusp.org/index.php/projects/current-projects/pacific-blue-shipping-partnership.

[44] See: https://ieep.eu/publications/greening-taxes-and-subsidies-in-the-pacific-islands

[45] See: https://www.adb.org/sites/default/files/publication/27511/pacific-fisheries.pdf

[46] Embedded in customary international law concerning the environment and climate change.

[47] Enshrined in the UN Framework Convention on Climate Change and Paris Agreement on Climate Change.

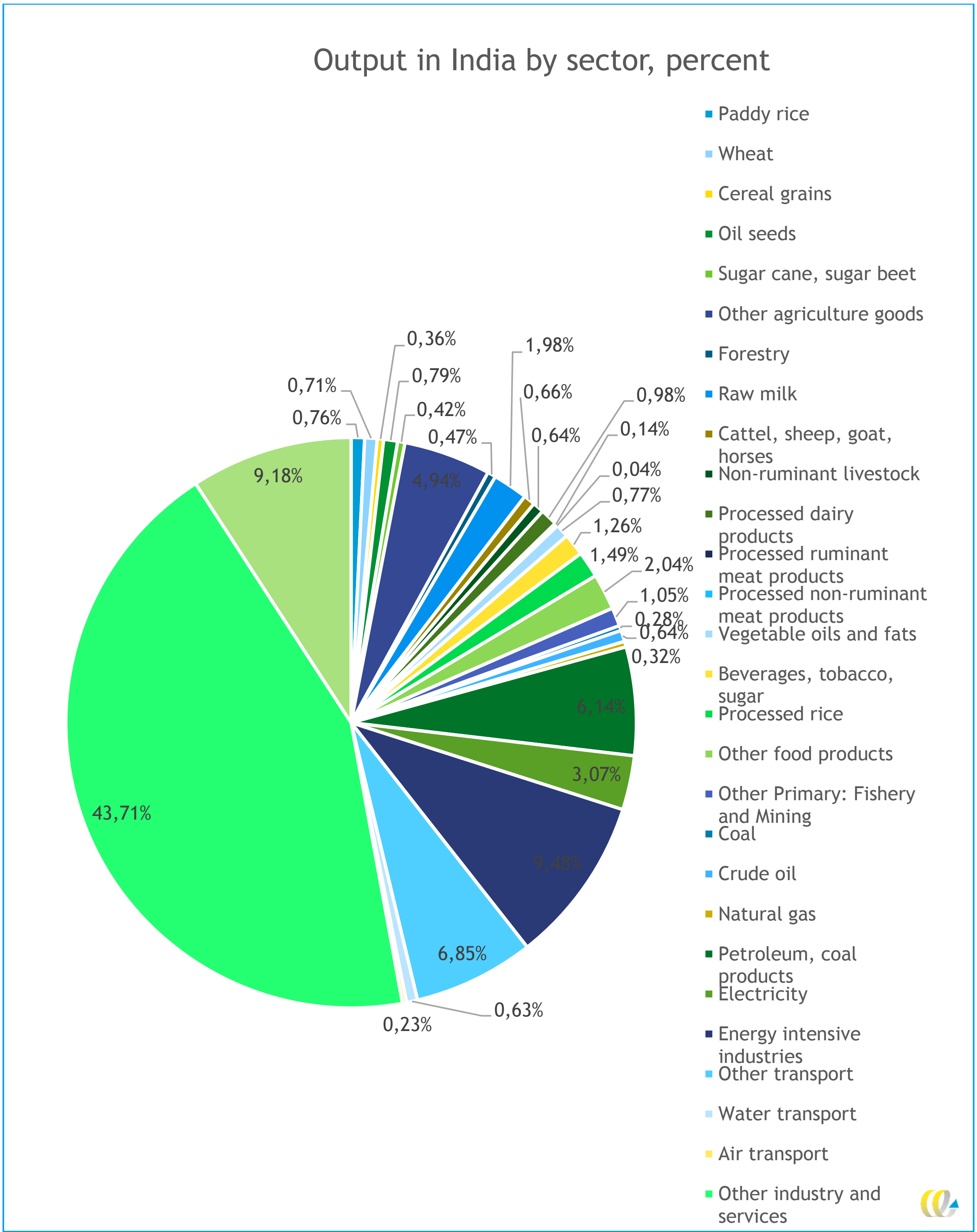
[48] Recognised in the 2030 Agenda for Sustainable Development.

maritime connectivity in the Pacific, given the prevalence noted above of smaller intra-country vessels.

7.2.2 India

In our set-up of the GTAP model, the largest sector in the Indian economy is the 'other industry and services' (responsible for 44% of the domestic output), followed by 'energy-intensive industries' (9%), non-tradable services (9%) and 'other transport, which is predominantly land-based transport (7%) (see Figure 6).

Figure 6 - Output by sector in India in the baseline, percent



As a result of measures that increase the use of low- and zero-carbon fuels in maritime transport and thereby the maritime transport costs, the model shows that the Indian economy as a whole will hardly be affected: GDP will increase by about one hundredth of a percent (see Section 6.1) and domestic output will increase by two to three hundredths of a percent. However, this result hides important changes between sectors.

As shown in Table 13 and Table 14, the output of some sectors will decrease. These tend to be sectors that export relatively low-value products and where the exports are negatively affected. In relative sense, processed ruminant meat products and other agricultural goods see the largest decline in output with 0.2 and 0.05%, respectively, in the low-fuel price scenario. The largest relative gains in output are in the energy-intensive industries, petroleum and coal products, and oil seeds. The output of these sectors will increase by 0.06-0.2%. Some of these sectors that are relatively much affected are small, whereas others are much larger, so a large relative impact does not equate a large absolute impact. The largest reductions in absolute output are 'other industries and services' and 'other agricultural products', respectively. The largest gains in output are in energy intensive industries and petroleum and coal products, respectively.

In general, Table 19 and Table 20 show that the impacts on the sectors are correlated with international trade: there is a weak positive correlation of output with exports, and a weak negative correlation with imports. In some cases, however, both exports and imports increase worst affected sectors international trade. These are, however, notable exceptions to this general rule. Both the exports and imports of the energy intensive industries increase, but the exports increase to a larger extent. One interpretation of this is that the international competitiveness of this sector increases: as a result its experts increase and for those exports, it requires an increase in imports of intermediary inputs. Because of the improved competitiveness, employment of the sector for both skilled and unskilled labor increases. This contrasts with the sector 'other industry and services'; this sector seems to lose international competitiveness as its exports are reduced while the imports increase. Consequently, employment in the sector is reduced.

In some sectors, a pattern of import substitution is visible: the imports of processed dairy products decrease, and employment in the sector increases. The output also increases. This suggests that products that were imported in the baseline are now produced domestically. Perhaps because of economies of scale, exports also increase. Similar patterns are visible for oil seeds, beverages, sugar and tobacco, and other food products.

A comparison of Table 19 and Table 20 shows that the impacts of low and high fuel prices show similar patterns, albeit that the impacts of high fuel prices are larger than those of low fuel prices.

Table 19 - Changes in output, employment and trade in India under low price CO_2 abatement with \$250/tCO_2 (effective carbon price \$125/tCO_2) emission price, percent

Sectors	Output	Exports	Imports	Skilled labor	Unskilled labor
Paddy rice	0.021	3.254	9.291	0.018	0.016
Wheat	0.003	-1.893	0.965	-0.001	-0.003
Cereal grains	-0.017	-0.194	7.292	-0.025	-0.027
Oil seeds	0.065	1.045	-0.137	0.069	0.067
Sugar cane, sugar beet	0.010	-0.782	3.014	0.004	0.003
Other agriculture goods	-0.054	-0.224	1.570	-0.070	-0.072
Forestry	-0.007	-0.297	-0.018	-0.004	-0.006
Raw milk	0.015	-1.239	1.584	0.010	0.009
Cattel, sheep, goat, horses	-0.011	-0.622	0.147	-0.021	-0.022
Non-ruminant livestock	0.008	-0.222	0.650	0.001	0.000
Processed dairy products	0.026	0.602	-0.521	0.033	0.025
Processed ruminant meat products	-0.168	-0.306	1.947	-0.161	-0.168

Sectors	Output	Exports	Imports	Skilled labor	Unskilled labor
Processed non-ruminant meat products	0.005	-0.026	0.470	0.012	0.005
Vegetable oils and fats	-0.048	0.552	0.132	-0.039	-0.046
Beverages, tobacco, sugar	0.007	-0.152	-0.037	0.015	0.007
Processed rice	-0.011	-0.252	2.457	-0.004	-0.012
Other food products	0.027	0.122	-0.054	0.033	0.026
Other Primary: Fishery and Mining	0.032	0.062	0.002	0.037	0.036
Coal	-0.009	-0.106	0.109	0.041	0.015
Crude oil	0.031	-0.039	0.123	0.044	0.041
Natural gas	-0.049	-0.134	0.359	-0.046	-0.048
Petroleum, coal products	0.109	0.306	-0.068	0.121	0.113
Electricity	0.037	-1.222	1.312	0.037	0.029
Energy intensive industries	0.229	0.984	0.020	0.236	0.228
Other transport	0.012	-0.085	0.211	0.027	0.016
Water transport	0.622	0.902	0.152	0.633	0.622
Air transport	-0.017	-0.029	0.085	-0.004	-0.015
Other industry and services	-0.037	-0.451	0.151	-0.029	-0.038
Non-tradable services	0.010	-0.702	0.201	0.014	0.006

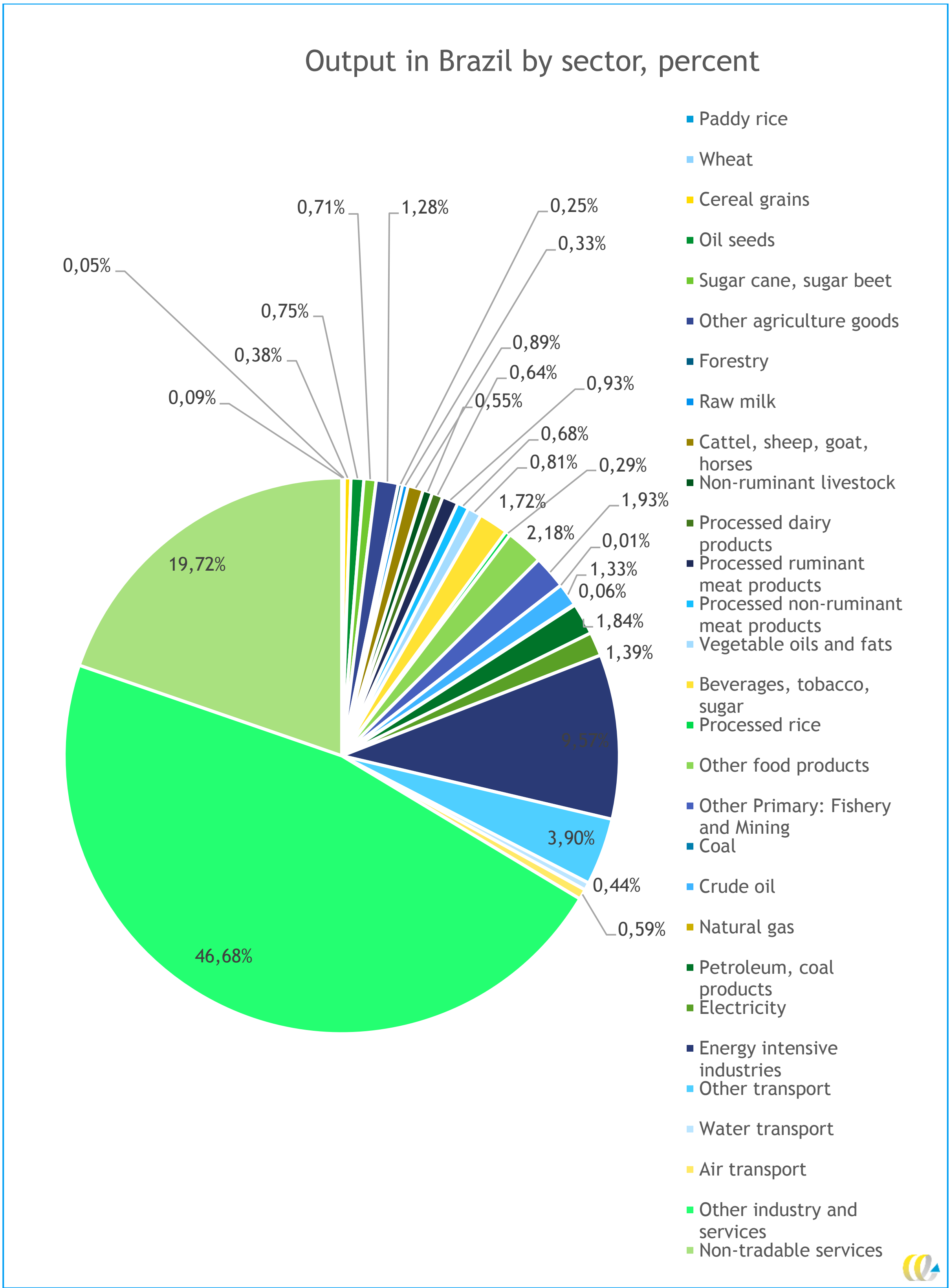
Table 20 - Changes in output, employment and trade in India under high price CO_2 abatement with \$400/tCO_2 (effective carbon price \$200/tCO_2) emission price, percent

Sectors	Output	Exports	Imports	Skilled labor	Unskilled labor
Paddy rice	0.035	5.249	14.597	0.030	0.027
Wheat	0.004	-3.022	1.522	-0.002	-0.005
Cereal grains	-0.026	-0.309	11.443	-0.040	-0.042
Oil seeds	0.104	1.676	-0.223	0.111	0.108
Sugar cane, sugar beet	0.016	-1.219	4.754	0.008	0.005
Other agriculture goods	-0.085	-0.348	2.465	-0.110	-0.113
Forestry	-0.010	-0.447	-0.031	-0.006	-0.009
Raw milk	0.024	-1.967	2.498	0.017	0.014
Cattel, sheep, goat, horses	-0.017	-0.988	0.234	-0.032	-0.035
Non-ruminant livestock	0.012	-0.354	1.014	0.003	0.000
Processed dairy products	0.042	0.960	-0.834	0.052	0.040
Processed ruminant meat products	-0.267	-0.487	3.063	-0.256	-0.268
Processed non-ruminant meat products	0.008	-0.048	0.750	0.019	0.007
Vegetable oils and fats	-0.075	0.888	0.211	-0.062	-0.074
Beverages, tobacco, sugar	0.012	-0.234	-0.060	0.024	0.012
Processed rice	-0.018	-0.399	3.884	-0.007	-0.019
Other food products	0.042	0.195	-0.087	0.053	0.041
Other Primary: Fishery and Mining	0.052	0.101	0.002	0.059	0.057
Coal	-0.016	-0.170	0.174	0.065	0.022
Crude oil	0.049	-0.070	0.198	0.070	0.065
Natural gas	-0.080	-0.219	0.574	-0.076	-0.079
Petroleum, coal products	0.175	0.495	-0.109	0.194	0.180
Electricity	0.059	-1.942	2.071	0.060	0.046
Energy intensive industries	0.363	1.561	0.031	0.375	0.362
Other transport	0.020	-0.137	0.337	0.044	0.026
Water transport	0.997	1.445	0.243	1.015	0.997
Air transport	-0.028	-0.047	0.135	-0.007	-0.025
Other industry and services	-0.059	-0.720	0.241	-0.046	-0.061
Non-tradable services	0.016	-1.121	0.321	0.023	0.010

7.2.3 Brasil

In our set-up of the GTAP model, the largest sector in the Brazilian economy is the ‘other industry and services’ (responsible for 47% of the domestic output), followed by non-tradable services (20%), and ‘energy-intensive industries’ (10%) (see Figure 7).

Figure 7 - Output in Brazil by sector, percent



As a result of measures that increase the use of low- and zero-carbon fuels in maritime transport and thereby the maritime transport costs, the model shows that the Brazilian economy as a whole will hardly be affected: GDP will increase by about one to two thousandth of a percent (see Paragraph 6.1) and domestic output will increase to the same extent. However, this result hides important changes between sectors.

As shown in Table 21 and Table 22, the output of some sectors will decrease. In relative sense, oil seeds, processed non-ruminant meat products, non-ruminant livestock and vegetable oil and fats see the largest decline in output with decreases of 0.1 to 0.3%. The largest gains in relative terms are seen in the 'other agricultural' sector, air transport, coal, and energy intensive industries with gains ranging from 0.04 to 0.07%. The increase of the output of air transport may point to mode shift, which could increase global GHG emissions. In absolute terms, the largest reductions in absolute output are oil seeds and petroleum and coal products, respectively. The largest gains in output are in energy intensive industries and other industry and services, respectively.

Like in the case of India, Table 19 and Table 20 show that the impacts on the sectors are correlated with international trade: there is a weak positive correlation of output with exports, but in contrast to the Indian case study, no correlation with imports. There is import substitution in processed dairy products, fossil fuels and energy intensive industries.

A comparison of Table 21 and Table 22 shows that the impacts of low and high fuel prices show similar patterns, albeit that the impacts of high fuel prices are larger than those of low fuel prices.

Table 21 - Changes in output, employment and trade in Brazil under low price CO_2 abatement with $250/t$CO_2$ (effective carbon price $125/t$CO_2$) emission price, percent

Sectors	Output	Exports	Imports	Skilled labor	Unskilled labor
Paddy rice	0.002	0.894	-0.036	-0.005	-0.005
Wheat	0.032	0.357	0.090	0.027	0.027
Cereal grains	-0.039	-0.102	0.012	-0.047	-0.048
Oil seeds	-0.335	-0.529	-0.017	-0.360	-0.361
Sugar cane, sugar beet	-0.014	-0.684	2.835	-0.021	-0.022
Other agriculture goods	0.067	0.216	-0.120	0.065	0.064
Forestry	0.004	-0.330	2.760	0.005	0.005
Raw milk	0.002	-1.098	0.996	-0.005	-0.005
Cattel, sheep, goat, horses	0.003	-0.261	0.215	-0.003	-0.003
Non-ruminant livestock	-0.149	-0.178	-0.159	-0.164	-0.164
Processed dairy products	0.002	-0.883	-0.192	0.002	0.001
Processed ruminant meat products	-0.068	-0.638	0.053	-0.069	-0.070
Processed non-ruminant meat products	-0.301	-0.734	0.140	-0.301	-0.302
Vegetable oils and fats	-0.083	-0.430	-0.486	-0.084	-0.085
Beverages, tobacco, sugar	-0.036	-0.162	-0.210	-0.037	-0.038
Processed rice	-0.023	-0.570	-0.101	-0.023	-0.024
Other food products	-0.013	-0.247	-0.282	-0.014	-0.015
Other Primary: Fishery and Mining	-0.034	-0.068	-0.199	-0.033	-0.033
Coal	0.050	0.298	-0.050	0.076	0.074
Crude oil	0.036	0.137	-0.349	0.047	0.047
Natural gas	0.002	0.280	-0.022	0.007	0.007
Petroleum, coal products	-0.055	-0.650	-0.066	-0.012	-0.013
Electricity	-0.025	-0.949	0.914	-0.029	-0.030
Energy intensive industries	0.037	-0.358	-0.341	0.042	0.041
Other transport	0.011	0.760	0.198	0.025	0.023
Water transport	0.178	0.597	0.154	0.197	0.195
Air transport	0.06	1.002	0.064	0.083	0.081
Other industry and services	0.006	-0.559	0.088	0.005	0.003
Non-tradable services	-0.004	-0.553	0.271	-0.007	-0.008

Table 22 - Changes in output, employment and trade in Brazil under high price CO_2 abatement with \$400/tCO_2 (effective carbon price \$200/tCO_2) emission price, percent

Sectors	Output	Exports	Imports	Skilled labor	Unskilled labor
Paddy rice	0.004	1.456	-0.063	-0.006	-0.007
Wheat	0.051	0.570	0.143	0.044	0.044
Cereal grains	-0.062	-0.161	0.018	-0.075	-0.076
Oil seeds	-0.533	-0.842	-0.033	-0.573	-0.573
Sugar cane, sugar beet	-0.022	-1.060	4.470	-0.033	-0.034
Other agriculture goods	0.111	0.357	-0.193	0.107	0.107
Forestry	0.006	-0.511	4.321	0.009	0.008
Raw milk	0.002	-1.735	1.566	-0.008	-0.008
Cattel, sheep, goat, horses	0.005	-0.416	0.334	-0.005	-0.005
Non-ruminant livestock	-0.239	-0.283	-0.256	-0.263	-0.263
Processed dairy products	0.004	-1.417	-0.307	0.003	0.001
Processed ruminant meat products	-0.109	-1.020	0.081	-0.110	-0.112
Processed non-ruminant meat products	-0.482	-1.176	0.221	-0.482	-0.484
Vegetable oils and fats	-0.132	-0.686	-0.779	-0.133	-0.135
Beverages, tobacco, sugar	-0.057	-0.257	-0.335	-0.058	-0.060
Processed rice	-0.037	-0.908	-0.164	-0.037	-0.039
Other food products	-0.021	-0.396	-0.451	-0.022	-0.023
Other Primary: Fishery and Mining	-0.053	-0.108	-0.319	-0.052	-0.052
Coal	0.080	0.486	-0.080	0.122	0.117
Crude oil	0.056	0.216	-0.555	0.074	0.074
Natural gas	0.002	0.432	-0.033	0.011	0.010
Petroleum, coal products	-0.088	-1.041	-0.105	-0.019	-0.021
Electricity	-0.040	-1.510	1.443	-0.046	-0.048
Energy intensive industries	0.058	-0.573	-0.545	0.067	0.065
Other transport	0.017	1.212	0.317	0.040	0.037
Water transport	0.285	0.957	0.247	0.315	0.312
Air transport	0.096	1.604	0.104	0.133	0.130
Other industry and services	0.009	-0.897	0.142	0.008	0.005
Non-tradable services	-0.007	-0.885	0.433	-0.011	-0.013

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A Initial Strategy's list of candidate mid- and long-term measures

In the Initial IMO Strategy the following list of candidate mid-term and long-term measures is given which is non-exhaustive according to the Strategy.

A.1 Cadidate mid-term measures

Measures can be categorized as:

- those the effect of which is to directly reduce GHG emissions from ships; and
- those which support action to reduce GHG emissions from ships.

All the following candidate measures represent possible mid-term further action of the Organization on matters related to the reduction of GHG emissions from ships:

1. Implementation programme for the effective uptake of alternative low- and zero-carbon fuels, including update of national actions plans to specifically consider such fuels.
2. Operational energy efficiency measures for both new and existing ships including indicators in line with three-step approach that can be utilized to indicate and enhance the energy efficiency performance of ships.
3. New/innovative emission reduction mechanism(s), possibly including Market-based Measures (MBMs), to incentivize GHG emission reduction.
4. Further continue and enhance technical cooperation and capacity-building activities such as under the ITCP.
5. Development of a feedback mechanism to enable lessons learned on implementation of measures to be collated and shared through a possible information exchange on best practice.

A.2 Candidate long-term measures

All the following candidate measures represent possible long-term further action of the Organization on matters related to the reduction of GHG emissions from ships:

1. Pursue the development and provision of zero-carbon or fossil-free fuels to enable the shipping sector to assess and consider decarbonization in the second half of the century.
2. Encourage and facilitate the general adoption of other possible new/innovative emission reduction mechanism(s).

B Design options

Design elements	Design options
Type of measure	Pricing mechanism
	Standard
	Funding
	Facilitation
	Obligation
Measure base	GHG emissions, technical/operational GHG efficiency, etc.
Type of target	Fleet target
	Per ship target
Stringency level	Uniform/differentiated levels
	Development over time
	Actual level(s)
Baseline	Level of aggregation (e.g. fleet, ship types and/or sizes)
	Historical period considered*
Scope	Geographic scope (all/some routes)
	Ship age/type/size
Revenues	Allocation mechanism
	Permitted purpose of use
Responsible entities	Compliance
	Enforcement
	Collection of revenues
	Allocation of revenues
	Disbursement of revenues

* Although the targets of the Initial IMO Strategy are related to 2008, the period on which the baseline(s) of a measure are determined could be different.

C Development of longlist

Table 23 – Overview of the different conceivable policy measures

	Measure base			
Type of measure	CO_2 emissions	Operational CO_2 efficiency	Determinants of operational CO_2 efficiency	Specific determinants of technical energy efficiency
Pricing mechanism	Cap&trade emissions trading scheme based on sector's annual CO_2 emissions Levy/tax based on ships' CO_2 emissions Baseline&credit scheme based on ships' annual CO_2 emissions Ship CO_2 emission standard & penalty/penalty&reward Subsidy for ships' CO_2 emission reductions	Baseline&credit scheme based on ships' operational CO_2 efficiency Ship operational CO_2 efficiency standard & penalty/penalty&reward	Baseline & credit scheme based on ships' technical CO_2 efficiency/technical energy efficiency/operational energy efficiency/speed/carbon intensity of energy consumption/share of renewable energy consumption/fossil carbon content of fuel Ship standard & penalty/penalty&reward for ships' technical CO_2 efficiency/technical energy efficiency/operational energy efficiency/speed/carbon intensity of energy consumption/share of renewable energy consumption/fossil carbon content of fuel Subsidy for ships' CO_2 emission reductions achieved by reduction of speed/carbon intensity of energy consumption/fossil carbon content of fuel Subsidy for ships' CO_2 emission reductions achieved by increase of share of renewable energy consumed	Baseline&credit scheme based on energy efficiency of ships' design/energy generating devices/energy consuming devices Ship standard & penalty/penalty&reward for energy efficiency of ships' design/energy generating devices/energy consuming devices Subsidy for ships' CO_2 emission reductions achieved by using a ship design/energy generating devices/energy consuming devices with an improved energy efficiency
Funding		Funding of adoption of measures that improve operational CO_2 efficiency of ships Rewarding relative CO_2 efficient ships	Funding of adoption of *specific* measures that improve operational CO_2 efficiency of ships R&D funding aimed at alternative fuels/smart logistical planning tools/improving port-ship communication Rewarding ships with relative high technical CO2 efficiency/technical energy efficiency.	Funding of adoption of *specific* measures that improve technical energy efficiency of ships R&D funding aimed at specific technical measures and/or ship designs Rewarding ships applying energy efficient energy generating/consuming devices
Standard	Ship CO_2 emission standard	Ship operational CO_2 effiency standard	Ship standard for ships' technical CO_2 efficiency/technichal energy efficiency/operational energy efficiency/speed/carbon intensity of energy consumption/renewable energy share/fossil carbon content of fuel	Ship standard for energy efficiency of ships' design/energy generating devices/energy consuming devices on board ships Standard for the shaft/engine power
Facilitating measure		Ship Operational CO_2 Efficiency Management Plan	SEEMP Implementation programme for effective uptake of low/zero-carbon fuels, including update of National Action Plans Technical cooperation and capacity building Facilitation of exchange of information/experience/best practice	Technical cooperation and capacity building Facilitation of exchange of information/experience/best practice
Obligation	Obligation to invest a certain amount in measures to reduce CO_2 emissions of ships	Obligation to check performance on a regular basis Obligation to invest a certain amount in measures to improve the operational CO_2 efficiency of ships	Obligation to adopt *specifc* measures to improve the operational CO_2 efficiency of ships Regular maintenance obligation Obligation to have ship-specific, third party on-board energy saving potential check-up	Obligation to adopt specific measures to improve the technial energy efficiency of ships Obligation to have ship-specific, third party on-board energy saving potential check-up

Table 24 – Longlist of potential supporting mid- and long-term measures

	Measure base			
Type of measure	CO_2 emissions	Operational CO_2 efficiency	Determinants of operational CO_2 efficiency	Specific determinants of technical energy efficiency
Pricing mechanism	Subsidy for ships' CO_2 emission reductions		Subsidy for ships' CO_2 emission reductions achieved by reduction of speed/carbon intensity of energy consumption/fossil carbon content of fuel Subsidy for ships' CO_2 emission reductions achieved by increase of share of renewable energy consumed	Subsidy for ships' CO_2 emission reductions achieved by using a ship design/energy generating devices/energy consuming devices with an improved energy efficiency
Funding		Funding of adoption of measures that improve operational CO_2 efficiency of ships Rewarding relative CO_2 efficient ships	Funding of adoption of *specific* measures that improve operational CO_2 efficiency of ships R&D funding aimed at alternative fuels/smart logistical planning tools/improving port-ship communication Rewarding ships with relative high technical CO_2 efficiency/technical energy efficiency.	Funding of adoption of *specific* measures that improve technical energy efficiency of ships R&D funding aimed at specific technical measures and/or ship designs Rewarding ships applying energy efficient energy generating/consuming devices
Standard			Ship standard for ships' technichal energy efficiency/operational energy efficiency/speed	Ship standard for energy efficiency of ships' design/energy generating devices/energy consuming devices on board ships Standard for the shaft/engine power
Facilitating measure		Ship Operational CO_2 Efficiency Management Plan	SEEMP Implementation programme for effective uptake of low/zero-carbon fuels, including update of National Action Plans Technical cooperation and capacity building Facilitation of exchange of information/experience/best practice	Technical cooperation and capacity building Facilitatation of exchange of information/experience/best practice
Obligation	Obligation to invest a certain amount in measures to reduce CO_2 emissions of ships	Obligation to check performance on a regular basis Obligation to invest a certain amount in measures to improve the operational CO_2 efficiency of ships	Obligation to adopt *specifc* measures to improve the operational CO_2 efficiency of ships Regular maintenance obligation Obligation to have ship-specific, third party on-board energy saving potential check-up	Obligation to adopt specific measures to improve the technial energy efficiency of ships Obligation to have ship-specific, third party on-board energy saving potential check-up

D GHG measure-related submissions to MEPC 60 and after MEPC

D.1 Submissions to MEPC 60

Table 25 – Market based measures analysed by the IMO MBM Expert Group

Measures analysed by the IMO MBM Expert Group		Proposed by	Submission	
Levy & offsetting scheme	An International Fund for Greenhouse Gas emissions from ships	Cyprus, Denmark, the Marshall Islands, Nigeria and IPTA	MEPC 60/4/8	https://www.transportstyrelsen.se/contentassets/a298eb269dc04bb5967a65a616d2ce9f/60-4-8.pdf
GHG fund & rebate to relative efficient ships	Leveraged Incentive Scheme (LIS) to improve the energy efficiency of ships based on the International GHG Fund	Japan	MEPC 60/4/37	https://www.transportstyrelsen.se/contentassets/a298eb269dc04bb5967a65a616d2ce9f/60-4-37.pdf
Port State fuel levy	Achieving reduction in greenhouse gas emissions from ships through Port State arrangements utilizing the ship traffic, energy and environment model, STEEM (PSL)	Jamaica	MEPC 60/4/40	https://www.transportstyrelsen.se/contentassets/a298eb269dc04bb5967a65a616d2ce9f/60-4-40.pdf
Baseline & credit scheme (technical efficiency)	The United States proposal to reduce greenhouse gas emissions from international shipping, the Ship Efficiency and Credit Trading (SECT)	United States	MEPC 60/4/12	https://www.transportstyrelsen.se/contentassets/a298eb269dc04bb5967a65a616d2ce9f/60-4-12.pdf
Technical standard with penalty	Vessel Efficiency System (VES)	World Shipping Council	MEPC 60/4/39	https://www.transportstyrelsen.se/contentassets/a298eb269dc04bb5967a65a616d2ce9f/60-4-39.pdf
ETS	Global Emission Trading System for international shipping	Norway	MEPC 60/4/22*	https://www.transportstyrelsen.se/contentassets/a298eb269dc04bb5967a65a616d2ce9f/60-4-22.pdf
ETS	Global Emission Trading System for international shipping	UK	MEPC 60/4/26	https://www.transportstyrelsen.se/contentassets/a298eb26

Measures analysed by the IMO MBM Expert Group		Proposed by	Submission	
				9dc04bb5967a65a6 16d2ce9f/60-4-26.pdf
ETS	Further elements for the development of an Emissions Trading System for International Shipping	France	MEPC 60/4/41	https://www.transportstyrelsen.se/contentassets/a298eb269dc04bb5967a65a616d2ce9f/60-4-41.pdf
[not a measure as such]	Market-Based Instruments: a penalty on trade and development	Bahamas	MEPC 60/4/10	https://www.transportstyrelsen.se/contentassets/a298eb269dc04bb5967a65a616d2ce9f/60-4-10.pdf
[not a measure as such]	A Rebate Mechanism (RM) for a market-based instrument for international shipping	IUCN	MEPC 60/4/55	https://www.transportstyrelsen.se/contentassets/a298eb269dc04bb5967a65a616d2ce9f/60-4-55.pdf

Source: MEPC 61/INF.2.

D.2 Submissions after MEPC 60

Cap & trade ETS		
MEPC 63/5/9	Design and Implementation of a worldwide maritime Emission Trading Scheme. Results of a scientific study	https://www.transportstyrelsen.se/contentassets/4b0bec76d2c74c95a37181b5fe45a921/63-5-9.pdf
MEPC 63/INF.14	Design and Implementation of a Worldwide Maritime Emission Trading Scheme Full Report	https://www.transportstyrelsen.se/contentassets/4b0bec76d2c74c95a37181b5fe45a921/63-inf14.pdf
MEPC 62/5/15	Possible uses of revenues generated by an Emissions Trading System	https://www.transportstyrelsen.se/contentassets/6c696ba2805c4302a019420184a056f0/62-5-15.pdf
MEPC 62/5/34	Comment on document MEPC 62/5/15 on the possible use of revenues generated by an Emissions Trading System	https://www.transportstyrelsen.se/contentassets/6c696ba2805c4302a019420184a056f0/62-5-34.pdf
GHG-WG 3/3/8/Rev.1	Implementation of an emissions trading system in two phases	https://www.transportstyrelsen.se/contentassets/e4571af6b5ab4b65ba74ce5738f239c1/3-3-8-rev1.pdf
GHG-WG 3/3/7	Cost-effectiveness and administrative costs of Market-Based Measures (ETS, GHG-fund, SECT)	https://www.transportstyrelsen.se/contentassets/e4571af6b5ab4b65ba74ce5738f239c1/3-3-7.pdf

Cap & trade ETS		
GHG-WG 3/3/6	Common features of proposals for a Global Emission Trading System (ETS) for International Shipping	https://www.transportstyrelsen.se/contentassets/e4571af6b5ab4b65ba74ce5738f239c1/3-3-6.pdf
GHG-WG 3/3/5	Examples of emission reductions and costs in a global Emission Trading System for international shipping	https://www.transportstyrelsen.se/contentassets/e4571af6b5ab4b65ba74ce5738f239c1/3-3-5.pdf
MEPC 60/4/54	Impact Assessment of an Emissions Trading Scheme with a particular view on developing countries	https://www.transportstyrelsen.se/contentassets/a298eb269dc04bb5967a65a616d2ce9f/60-4-54.pdf
MEPC 60/4/43	Common features on documents submitted on a Global Emission Trading System (ETS) for International Shipping	https://www.transportstyrelsen.se/contentassets/a298eb269dc04bb5967a65a616d2ce9f/60-4-43.pdf
MEPC 60/4/41	Further elements for the development of an Emissions Trading System for International Shipping	https://www.transportstyrelsen.se/contentassets/a298eb269dc04bb5967a65a616d2ce9f/60-4-41.pdf
MEPC 60/4/26	A global emissions trading system for greenhouse gas emissions from international shipping	https://www.transportstyrelsen.se/contentassets/a298eb269dc04bb5967a65a616d2ce9f/60-4-26.pdf
MEPC 60/4/22	A further outline of a Global Emission Trading System (ETS) for International Shipping	https://www.transportstyrelsen.se/contentassets/a298eb269dc04bb5967a65a616d2ce9f/60-4-22.pdf
MEPC 60/INF.8	Practical aspects of a global emissions trading scheme for international shipping	https://www.transportstyrelsen.se/contentassets/a298eb269dc04bb5967a65a616d2ce9f/60-inf8.pdf

Levy/tax		
MEPC 64/5/4	Elaboration on the Port State Levy proposal	https://www.transportstyrelsen.se/contentassets/bba8fb5ccaac4c378fcedf299b6bddb2/64-5-4.pdf
MEPC 60/4/51	Comments on MEPC 60/4/8, ‘An International Fund for Greenhouse Gas emissions from ships’	https://www.transportstyrelsen.se/contentassets/a298eb269dc04bb5967a65a616d2ce9f/60-4-51.pdf
MEPC 60/4/49	An International Fund for Greenhouse Gas emissions from ships	https://www.transportstyrelsen.se/contentassets/a298eb269dc04bb5967a65a616d2ce9f/60-4-49.pdf
MEPC 60/4/8	An International Fund for Greenhouse Gas emissions from ships	https://www.transportstyrelsen.se/contentassets/a298eb269dc04bb5967a65a616d2ce9f/60-4-8.pdf
MEPC 60/INF.7	Effects on sea transport cost due to an International Fund for GHG emission for ships	https://www.transportstyrelsen.se/contentassets/a298eb269dc04bb5967a65a616d2ce9f/60-inf7.pdf
GHG-WG 3/3/4	The International Greenhouse Gas Fund	https://www.transportstyrelsen.se/contentassets/e4571af6b5ab4b65ba74ce5738f239c1/3-3-4.pdf

Levy/tax		
MEPC 60/4/40	Achieving reduction in greenhouse gas emissions from ships through Port State arrangements utilizing the ship traffic, energy and environment model, STEEM	https://www.transportstyrelsen.se/contentassets/a298eb269dc04bb5967a65a616d2ce9f/60-4-40.pdf
MEPC 57/4/4	A global levy on marine bunkers, primarily to be applied for the acquisition of CO_2 emission quotas through the purchase of CO_2 credits	https://www.transportstyrelsen.se/contentassets/755d2d5b985d4df09d3b62d1aa91a5ae/57-4-4.pdf
MEPC 57/INF.13	A global levy on marine bunker, primarily to be applied for the acquisition of CO_2 emission quotas through the purchase of CO_2 credits	https://www.transportstyrelsen.se/contentassets/755d2d5b985d4df09d3b62d1aa91a5ae/57-inf13.pdf

Operational efficiency measure		
MEPC 74/7/4	Proposal for a goal-based short-term reduction measure	https://www.transportstyrelsen.se/contentassets/cc9a6651e83046e8a5f78cf92ceb231f/74-7-4.pdf
MEPC 74/7/16	Comments on document MEPC 74/7/4	http://www.ics-shipping.org/docs/default-source/Submissions/comments-on-document-mepc-74-7-4.pdf?sfvrsn=0
ISWG-GHG 4/2/9	Review of candidate measures to reduce GHG emissions from international shipping	https://www.transportstyrelsen.se/contentassets/dae674e69d644555855fe2afe5ff6526/4-2-9.pdf
MEPC 72/7/1	Understanding CO_2 emissions and challenges in assessing the operational efficiency for ships	https://www.transportstyrelsen.se/contentassets/57f800efae134fe0af0808d2773a14f2/72-7-1.pdf
MEPC 72/INF.5	Understanding CO_2 emissions and challenges in assessing the operational efficiency for ships	https://www.transportstyrelsen.se/contentassets/57f800efae134fe0af0808d2773a14f2/72-inf5.pdf
ISWG-GHG 2/2/7	Statistical analysis on the characteristics of operational energy efficiency of ships and the properties of regression lines of the potential indicator	https://www.transportstyrelsen.se/contentassets/d5d35c29fb4d4f91b849afb70309a521/2-2-7.pdf
ISWG-GHG 1/2/1	Input to the Roadmap – Technical evaluation and further process on the indicators on energy efficiency in the three step approach	https://www.transportstyrelsen.se/contentassets/d092349627db439ab8491bda8044cc0a/1-2-1.pdf
MEPC 69/6/6	Economic, technical, commercial and practical issues related to definition and implementation of mandatory operational efficiency standards	https://www.transportstyrelsen.se/contentassets/bd17c67d76494ab9991463e37bdcf92d/69-6-6.pdf

Operational efficiency measure		
MEPC 69/INF.28	Economic, technical, commercial and practical issues related to definition and implementation of mandatory operational efficiency standards	https://www.transportstyrelsen.se/contentassets/bd17c67d76494ab9991463e37bdcf92d/69-inf28.pdf
MEPC 69/6/4	Non-viability of establishing an operational efficiency standard for existing ships	https://www.transportstyrelsen.se/contentassets/bd17c67d76494ab9991463e37bdcf92d/69-6-4.pdf
MEPC 69/INF.26	Understanding the Energy Efficiency Operational Indicator (EEOI) and analysing CO_2 emissions from ships	https://www.transportstyrelsen.se/contentassets/bd17c67d76494ab9991463e37bdcf92d/69-inf26.pdf
MEPC 69/INF.21	Findings from a study on the use of transport work parameters to determine the energy efficiency of existing ships	https://www.transportstyrelsen.se/contentassets/bd17c67d76494ab9991463e37bdcf92d/69-inf21.pdf
MEPC 68/INF.29	Empirical comparative analysis of energy efficiency indicators for ships	https://www.transportstyrelsen.se/contentassets/32254a1d13534faf854c22c38db18d8b/68-inf29.pdf
MEPC 68/INF.24/Rev.1	The Existing Shipping Fleet's CO_2 Efficiency	https://www.transportstyrelsen.se/contentassets/32254a1d13534faf854c22c38db18d8b/68-inf24-rev1.pdf
MEPC 68/4/9	Policy and practical issues that arise with mandatory operational efficiency standards	https://www.transportstyrelsen.se/contentassets/32254a1d13534faf854c22c38db18d8b/68-4-9.pdf
MEPC 68/4/3	Suitability of further measures to enhance energy efficiency in international shipping	https://www.transportstyrelsen.se/contentassets/32254a1d13534faf854c22c38db18d8b/68-4-3.pdf
MEPC 67/5/6	Operational consequences of operational efficiency standards	https://www.transportstyrelsen.se/contentassets/dc0f73c2603d407cb410de5ff36428fb/67-5-6.pdf
MEPC 67/5/4	Further consideration on the development of a data collection system to enhance energy efficiency of international shipping	https://www.transportstyrelsen.se/contentassets/dc0f73c2603d407cb410de5ff36428fb/67-5-4.pdf
MEPC 67/5	Mandatory operational efficiency standards: Should the IMO pursue development of fleet-wide operational efficiency standards?	https://www.transportstyrelsen.se/contentassets/dc0f73c2603d407cb410de5ff36428fb/67-5.pdf
MEPC 66/4/25	Comments on enhancing energy efficiency in international shipping	https://www.transportstyrelsen.se/contentassets/98b9af326ccd441292fe7af9433f6a90/66-4-25.pdf
MEPC 66/4/14	Comments on document MEPC 66/4/6 and on document MEPC 66/4/19	https://www.transportstyrelsen.se/contentassets/98b9af326ccd441292fe7af9433f6a90/66-4-14.pdf
MEPC 66/4/6	Further details of possible metric options to develop further technical and operational measures for enhancing the	https://www.transportstyrelsen.se/contentassets/98b9af326ccd441292fe7af9433f6a90/66-4-6.pdf

Operational efficiency measure		
	energy efficiency of international shipping	
MEPC 65/4/30	Comments on document MEPC 65/4/19 on enhancing energy efficiency in international shipping	https://www.transportstyrelsen.se/contentassets/5173f23809a149a78678b1850f876738/65-4-30.pdf
MEPC 65/4/19	Proposal of the United States to enhance energy efficiency in international shipping	https://www.transportstyrelsen.se/contentassets/5173f23809a149a78678b1850f876738/65-4-19.pdf
MEPC 64/5/6	Further details on the proposal of the United States to reduce greenhouse gas emissions from international shipping	https://www.transportstyrelsen.se/contentassets/bba8fb5ccaac4c378fcedf299b6bddb2/64-5-6.pdf
MEPC 64/5/11	Operational energy efficiency of new and existing ships	https://www.transportstyrelsen.se/contentassets/bba8fb5ccaac4c378fcedf299b6bddb2/64-5-11.pdf

Technical efficiency measure including existing ships (incl. pricing mechanisms and standard & penalty)		
MEPC 69/INF.8	The implementation of technical energy efficiency measures in shipping	https://www.transportstyrelsen.se/contentassets/bd17c67d76494ab9991463e37bdcf92d/69-inf8.pdf
MEPC 64/INF.15	Schematic outline of the modified Efficiency Incentive Scheme (EIS)	https://www.transportstyrelsen.se/contentassets/bba8fb5ccaac4c378fcedf299b6bddb2/64-inf15.pdf
MEPC 64/5/2	Draft legal text on the modified Efficiency Incentive Scheme (EIS)	https://www.transportstyrelsen.se/contentassets/bba8fb5ccaac4c378fcedf299b6bddb2/64-5-2.pdf
MEPC 63/5/3	Efficiency Incentive Scheme (EIS)	https://www.transportstyrelsen.se/contentassets/4b0bec76d2c74c95a37181b5fe45a921/63-5-3.pdf
MEPC 63/5/12	Application of the EEDI to Existing Ships	https://www.transportstyrelsen.se/contentassets/4b0bec76d2c74c95a37181b5fe45a921/63-5-12.pdf
GHG-WG 3/3/2	Consolidated proposal of 'Efficiency Incentive Scheme' based on the Leveraged Incentive Scheme and the Vessel Efficiency System	https://www.transportstyrelsen.se/contentassets/e4571af6b5ab4b65ba74ce5738f239c1/3-3-2.pdf
MEPC 61/5/16	Further details on the United States proposal to reduce greenhouse gas emissions from international shipping	https://www.transportstyrelsen.se/contentassets/78286261e8ba45918973ccb2fd63af33/61-5-16.pdf
MEPC 61/INF.24	Further details on the US proposal to reduce greenhouse gas emissions from international shipping	https://www.transportstyrelsen.se/contentassets/78286261e8ba45918973ccb2fd63af33/61-inf24.pdf

Technical efficiency measure including existing ships (incl. pricing mechanisms and standard & penalty)		
MEPC 60/4/37	Leveraged Incentive Scheme (LIS) to improve the energy efficiency of ships based on the International GHG Fund	https://www.transportstyrelsen.se/contentassets/a298eb269dc04bb5967a65a616d2ce9f/60-4-37.pdf

Market based measures		
ISWG-GHG 4/2/11	Proposal to include work on Market-based Measures in the programme of follow-up actions of the Initial IMO GHG Strategy	https://www.transportstyrelsen.se/contentassets/dae674e69d644555855fe2afe5ff6526/4-2-11.pdf
MEPC 63/5/10	Measures to reduce greenhouse gas emissions from ships	https://www.transportstyrelsen.se/contentassets/4b0bec76d2c74c95a37181b5fe45a921/63-5-10.pdf
MEPC 63/5/8	Market Based Measures – Impact on India's shipping trade	https://www.transportstyrelsen.se/contentassets/4b0bec76d2c74c95a37181b5fe45a921/63-5-8.pdf
MEPC 62/5/14	Ensuring no net incidence on developing countries from a global maritime MBM	https://www.transportstyrelsen.se/contentassets/6c696ba2805c4302a019420184a056f0/62-5-14.pdf
MEPC 62/5/7	MBM proposals: a way ahead	https://www.transportstyrelsen.se/contentassets/6c696ba2805c4302a019420184a056f0/62-5-7.pdf
GHG-WG 3/3/7	Cost-effectiveness and administrative costs of Market-Based Measures	https://www.transportstyrelsen.se/contentassets/e4571af6b5ab4b65ba74ce5738f239c1/3-3-7.pdf
GHG-WG 3/3/3	The IMO, global MBMs that reduce emissions and the question of Principles	https://www.transportstyrelsen.se/contentassets/e4571af6b5ab4b65ba74ce5738f239c1/3-3-3.pdf
GHG-WG 3/2/1	How an MBM can reduce GHG emissions	https://www.transportstyrelsen.se/contentassets/e4571af6b5ab4b65ba74ce5738f239c1/3-2-1.pdf
MEPC 61/5/39	Report on the outcome of the work undertaken by the Expert Group on Feasibility Study and Impact Assessment of possible Market-based Measures (MBM-EG)	https://www.transportstyrelsen.se/contentassets/78286261e8ba45918973ccb2fd63af33/61-5-39.pdf
MEPC 60/4/13	Control of greenhouse gas emissions from international maritime transport	https://www.transportstyrelsen.se/contentassets/a298eb269dc04bb5967a65a616d2ce9f/60-4-13.pdf

Ship emission standard		
MEPC 63/5/1	Draft regulations to be included in MARPOL Annex VI for the control of CO_2 emissions from ships	https://www.transportstyrelsen.se/contentassets/4b0bec76d2c74c95a37181b5fe45a921/63-5-1.pdf
MEPC 62/5/13	Mandatory CO_2 emission cut targets through technical and operational measures	https://www.transportstyrelsen.se/contentassets/6c696ba2805c4302a019420184a056f0/62-5-13.pdf
GHG-WG 3/2	How technical and operational measures are the only direct and effective means to deliver cuts in CO_2 emissions	https://www.transportstyrelsen.se/contentassets/e4571af6b5ab4b65ba74ce5738f239c1/3-2.pdf

E Details on the assessment of the long-listed measures

E.1 Explanation of score levels per criterion

Table 26 – Explanation of score level per criterion

	Cost-effectiveness of measure type	Range of reduction options directly incentivized	Incentive uptake of low/zero-carbon fuels at relative early stage	Administrative costs	Certainty with which emissions pathway can be followed	Potential implementation hurdles from social/ administrations perspective	Costs for remaining emissions	Certainty of compliance costs	Potential major objectives of sector
++	Measure is cost-effective	Adoption of all emission reduction measures is directly incentivized	Highest incentive (directly targeted/ highest incentive)	Lowest expected administrative costs	Emissions pathway can rightly be followed (Growth of fleet & increase of activity of ships both *cannot* counteract)		No costs accrue for remaining emissions	Highest certainty (no price/ exogenous price)	
+		A large range of all emission reduction measures is directly incentivized	High incentive (high incentive)	Relative low expected administrative costs	Increase of activity of ships can counteract, but not growth of fleet due to the fleet average target			Relative certain	
0	Measure might be cost-effective	A medium range of all emission reduction measures is directly incentivized	Medium incentive (medium range of reduction measures)	Medium expected administrative costs	Growth of fleet can counteract, but not the increase of activity of ships		For parts of the fleet, costs for the remaining emissions above a	Medium certainty	

	Cost-effectiveness of measure type	Range of reduction options directly incentivized	Incentive uptake of low/zero-carbon fuels at relative early stage	Administrative costs	Certainty with which emissions pathway can be followed	Potential implementation hurdles from social/ administrations perspective	Costs for remaining emissions	Certainty of compliance costs	Potential major objectives of sector
							benchmark accrue		
-		A relative small range of all emission reduction measures is directly incentivized	Low incentive (broad range of reduction measure)	Relative high expected administrative costs	Growth of fleet & increase of activity of ships *can* counteract/ Growth of fleet (but not increase of activity of ships) can counteract + measure as such is associated with uncertainty			Relative uncertain	
--	Measure probably not cost effective	A limited subset of all emission reduction measures is directly incentivized.	Lowest incentive (broadest range of reduction measures)	Highest expected administrative costs	Growth of fleet & increase of activity of ships *can* counteract + measure as such is associated with uncertainty	Revenues that are first collected by decentral administrations to then be collected by a central administration: hypothecation of the revenues might become a political issue in some countries	Costs accrue for the entire remaining emissions	Highest uncertainty (endogenous price)	Measures with ‘operational efficiency’ as (potential) measure base Measures the design of which relies on ‘operational efficiency’

E.2 Assessment criteria from social/administrations' perspective

Compliance costs

Three indicators for the assessment of the measures' compliance costs are used:

1. The cost effectiveness of the measure types.
2. The range of the reduction measures the environmental measures incentivize.
3. The incentive for the uptake of low/zero fossil carbon fuels at a relative early stage.

Table 27 – Cost effectiveness of measure type

	Explanation of score levels	Measure ranking
++	Measure is cost-effective	Cap & trade ETS Levy/tax Baseline & credit scheme
+		
0	Measure might be cost-effective	Feebate scheme
-		
--	Measure probably not cost effective	Standard & penalty scheme

An environmental measure is considered to implement an efficient allocation, if it leads to equal marginal emission abatement costs across the regulated actors, i.e. if the costs for the last emitted unit of emission is equal for each of them. The same conditions holds should a politically set target be met against the lowest costs. Environmental measures leading to equal marginal abatement costs are therefore also referred to as cost effective measures.

A cap & trade ETS, a levy/tax scheme and a baseline & credit scheme are cost effective measures — a baseline & credit scheme, if targeting the CO_2 emissions of ships, is equal to a cap & trade emission with free allowances, with the only difference that under a baseline & credit scheme ships do not have to submit emission credits if their emission level is beneath the baseline.

A feebate scheme could be equivalent to a baseline & credit scheme, however, the fee rate and the rebate rate might differ, potentially leading to different values of emission units above and below the standard.

Standard & penalty scheme is probably not cost effective, since a reduction of the emissions below the standard is not rewarded. Ships for which holds that the marginal abatement costs at the threshold value (=standard) are lower than the penalty rate (applied to emissions) have an incentive to emit emissions at the threshold level which is an emission level that is higher than the emission level that ships would emit under for example a tax/levy regime.

Note that the effectiveness of a measures also depends on whether an absolute measure base (CO_2) or a relative measure base (carbon intensity) is selected. We will consider this by means of the criterion 'Certainty with which an emissions pathway can be followed' (see Appendix E.2.3).

The broader the range of the emission reduction measures that the policy measure directly incentivizes, the lower the compliance costs of the policy measure can be expected. Measures targeting the ships' CO_2 emission can therefore be expected to be associated with relative low compliance costs and measures targeting the carbon intensity of energy consumption or fuel with relative high compliance costs (Table 28).

Table 28 – Range of reduction options directly incentivized

	Explanation of score levels	Measure ranking
		Measures targeting…
++	Adoption of all emission reduction measures is directly incentivized.	• CO_2 emissions
+	A large range of all emission reduction measures is directly incentivized	• operational GHG efficiency
0	A medium range of all emission reduction measures is directly incentivized	• technical GHG efficiency standard
-	A relative small range of all emission reduction measures is directly incentivized	• carbon intensity of energy consumption or fuel
--	A limited subset of all emission reduction measures is directly incentivized.	

If compliance with a mid-/long-term measure required the use of low/zero fossil carbon fuels, the sector might face high compliance costs if their TRL was still rather low.
If however policy measures incentivize the uptake of low/zero fossil carbon fuels at a relative early stage, the development of the fuels can be expected to advance at an earlier stage. For this reason we assess measures that incentive the uptake of low/zero fossil carbon fuels at a relative early stage to be associated with lower compliance costs. These are measures that incentivize a rather narrow range of emission reduction measures, including low/zero fossil carbon fuels.

Table 29 – Incentive for the uptake of low/zero fossil carbon fuels at a relative early stage

	Explanation of score levels	Measure ranking
		Measures targeting…
++	Highest incentive (directly targeted/highest incentive)	• carbon intensity of energy consumption or fuel
+	High incentive (high incentive)	
0	Medium incentive (medium range of reduction measures)	• technical CO_2 efficiency
-	Low incentive (broad range of reduction measure)	• operational CO_2 efficiency
--	Lowest incentive (broadest range of reduction measures)	• CO_2 emissions

Administrative costs

Table 30 – Administrative costs for administrations and sector

	Explanation	Measure ranking
++	Lowest expected administrative costs	Levy/tax (no centralized revenue collection)
+	Relative low expected administrative costs	Standard & penalty scheme Levy/tax (with centralized revenue collection) Baseline & credit scheme
0	Medium expected administrative costs	Feebate scheme
-	Relative high expected administrative costs	Cap & trade ETS (auctioning of allowances; no centralized revenue collection)
--	Highest expected administrative costs	Cap & trade ETS (auctioning of allowances with centralized revenue collection) Cap & trade ETS (free allowances)

Explanation:

In Table 30, the different administrative tasks that can be expected in general (see first row) and can be expected per measure type are listed. For the administrations, two different phases are thereby differentiated, i.e. the implementation phase and the operational phase of the measures.

Based on these different requirements, we have qualitatively assessed the different measures per phase. Regarding the implementation phase, policy development and whether or not a central administration has to be established are thereby explicitly distinguished. The according ranking of the measure is given in Table 31.

Table 31 – Overview of administrative tasks per measure and phase

		Administrations		Sector
		Implementation phase	Operational phase	Operational phase
General tasks, independent of measure		Establishment of decentral administrations* + …	Monitoring + Enforcement by decentral administrations + …	Establishment of administration + MRV + coordination of reduction/emission levels + …
Standard & penalty scheme		…determination of standard(s) and penalty	…penalty collection by decentral administrations	…payment of penalty if necessary
Feebate scheme		…determination of standard(s) and fee** + establishment of a central administration	…collection of fee by decentral administrations to be transferred to central administration + central administration to calculate rebate rate and to disburse rebates	…payment of fee if necessary/ application for rebate if possible
Levy/tax	No centralized revenue collection	…determination of levy/tax rate	…collection of tax/levy by decentral administrations	…payment of tax/levy
	+centralized revenue collection	…determination of levy/tax rate + establishment of central administration (e.g. fund)	…collection of tax/levy by decentral administrations to be transferred to central administration + central administration to coordinate use of total revenues	…payment of tax/levy
Cap & trade ETS (free allowances)		…establishment of total amount of allowances to be issued +	…issuance and collection of allowances by	…request for free allowances + emissions trading

		Administrations		Sector
		Implementation phase	Operational phase	Operational phase
		establishment of mode for allocation of allowances to ships	decentral administrations	+ submission of allowances
Cap & trade ETS (auctioning of allowances)	No centralized revenue collection	…establishment of total amount of allowances to be auctioned + establishment of mode for allocation of allowances to decentral administrations	…auctioning of allowances by decentral administrations at one/several existing auctioning platforms + collection of allowances by decentral administrations	…buying allowances + emissions trading + submission of allowances
	+centralized revenue collection	…establishment of total amount of allowances + establishment of mode for allocation of allowances to decentral administrations + establishment of central administration	…auctioning of allowances by decentral administrations at one/several existing auctioning platforms + revenues to be transferred from decentral administrations to central administration + central administration to coordinate use of total revenues + collection of allowances by decentral administrations	…buying allowances + emissions trading + submission of allowances
Baseline & credit scheme		…determination of standard(s)	…issuance and collection of credits by decentral administrations	…request for credits if possible+ credit trading if desired/required + submission of credits if necessary

* For example as part of Flag State administration.

** Level of rebate is endogenously determined.

Table 32 – Ranking of the measures per phase based on qualitative assessment of tasks specified in Table 31 (above)

	Implementation phase		Operational phase administrations	Operational phase sector
	Policy development	Central administration needs to be established		
++	Levy/tax (with/no centralized revenue collection)		Standard & penalty scheme	Standard & penalty scheme Levy/tax (with/no centralized revenue collection) Feebate scheme
+			Feebate scheme Levy/tax (with/no centralized revenue collection)	
0	Cap & trade ETS (auctioning of allowances with/no centralized revenue collection)	Standard & penalty scheme Levy/tax (no centralized revenue collection) Cap & trade ETS (auctioning of allowances; no centralized revenue collection) Cap & trade ETS (free allowances) Baseline & credit scheme	Cap & trade ETS (auctioning of allowances with/no centralized revenue collection)	Baseline & credit scheme
-	Baseline & credit scheme Cap & trade ETS (free allowances)		Baseline & credit scheme	Cap & trade ETS (free allowances)
--	Feebate scheme Standard & penalty scheme	Feebate scheme Levy/tax (with centralized revenue collection) Cap & trade ETS (auctioning of allowances with centralized revenue collection)	Cap & trade ETS (free allowances)	Cap & trade ETS (auctioning of allowances with/no centralized revenue collection)

The administrative costs associated with the development of a tax/levy are expected to be lowest, since only a levy/tax rates would need to be established.

The development of policy measures that require the establishment of a baseline (baseline & credit scheme, cap & trade ETS with free allowances, feebate scheme and standard & penalty scheme) is expected to be relatively high, with the feebate scheme and the standard & penalty scheme also requiring the establishment of a fee/a penalty.

Medium administrative costs are expected to be associated with the development of a cap & trade ETS, where the total amount of emissions needs as well as a mode for the allocation of the allowances to the decentral administrations is required.

Regarding, the administrations' administrative costs in the operational phase of the measures, for each of the measures, administrations would need to control for each ship whether it is compliant or not.
In addition, a cap & trade ETS and a baseline & credit scheme would both require administrations to issue and collect emissions allowances/credits. The issuance of the emission allowances by means of auctions can thereby be expected to be associated with relative lower costs. And the baseline & credit scheme would, if compared with a cap & trade ETS with free allocation of allowances require the issuance and collection of credits to/from a smaller number of ships.

If a standard & penalty scheme, a levy/tax scheme and a feebate scheme were implemented, administration would not need to hand out credits/emissions allowances, reducing their administrative burden for each of the three measuers. A standard & penalty scheme however is associated with less administrative work compared to a levy/tax since a penalty would need to be collected from a smaller number of ships. The same holds for a feebate scheme, however a feebate scheme is also associated with administrative costs for the disbursement of the rebate.

Regarding, the sector's administrative costs in the operational phase, a standard & penalty scheme, a levy/tax, and a feebate scheme can be expected to be associated with the lowest costs. The effort would be limited to the payment of a penalty/tax/levy/fee or to requesting a rebate under a feebate scheme.

Under a cap & trade ETS, all ships would have to submit allowances and would have to make sure that they dispose of the right amount of allowances, with an auction adding another dimension of complexity.

Under a baseline & credit scheme only a subset of ships would have sell/acquire credits, but credit trading is still required, making it more complex than a standard & penalty scheme or levy/tax scheme or a feebate scheme.

Given the implementation phase less (half) weight than the operational phase and considering that the social perspective considers both, the administrations and the sector, the following overall ranking of the measures is established:

Table 33 – Ranking of measures based on their expected administrative costs

	Social perspective/administrations perspective (incl. sector)	Sector perspective
++	Levy/tax (no centralized revenue collection) Levy/tax (with centralized revenue collection) Standard & penalty scheme	Standard & penalty scheme Levy/tax (with/no centralized revenue collection) Feebate scheme
+		
0	Feebate scheme	Baseline & credit scheme
-	Baseline & credit scheme Cap & trade ETS (auctioning of allowances; no centralized revenue collection)	Cap & trade ETS (free allowances)
--	Cap & trade ETS (auctioning of allowances with centralized revenue collection) Cap & trade ETS (free allowances)	Cap & trade ETS (auctioning of allowances with/no centralized revenue collection)

Certainty with which an emissions pathway can be followed

Table 34 – Certainty with which an emissions pathway can be followed

	Explanation of score levels	Measure ranking
++	Emissions pathway can rightly be followed (Growth of fleet & increase of activity of ships both ***cannot*** counteract)	Cap & trade ETS (CO_2) Baseline & credit scheme (CO_2)
+	Increase of activity of ships can counteract, but not growth of fleet due to the fleet average target	Baseline & credit scheme (carbon intensity)
0	Growth of fleet can counteract, but not the increase of activity of ships	Levy/tax (CO_2) Feebate scheme (CO_2)
-	Growth of fleet & increase of activity of ships *can* counteract/ Growth of fleet (but not increase of activity of ships) can counteract + measure as such is associated with uncertainty	Feebate scheme (carbon intensity) Standard & penalty scheme (CO_2)
--	Growth of fleet & increase of activity of ships *can* counteract + measure as such is associated with uncertainty	Standard & penalty scheme (carbon intensity)

Note that this is about meeting a politically set emissions pathway and not meeting the socially optimal emissions level which can increase with an increasing number of ships.

Potential implementation hurdles

Table 35 – Potential implementation hurdles from social/administrations perspective

	Explanation of score levels	Measure ranking
++		
+		
0		
-		
--	Revenues that are first collected by decentral administrations to then be collected by a central administration: hypothecation of the revenues might become a political issue in some countries	• cap & trade ETS (auctioning of allowances with centralized revenue collection) • levy/tax (with centralized revenue collection) • feebate scheme

E.3 Sector perspective criteria

Compliance costs

See Table 27, 28 and Table 29 under Section E.2 for:

- cost-effectiveness of measure type;
- range of reduction options directly incentivized;
- incentive for the uptake of low/zero-carbon fuels at a relative early stage.

Table 36 – Costs for the remaining emissions

	Explanation of score levels	Measure ranking
++	No costs accrue for emissions/carbon intensity below baseline/standard	• cap & trade ETS (free allowances) • baseline & credit scheme • standard & penalty scheme • feebate scheme
+		
0		
-		
--	Costs accrue for remaining emissions	• cap & trade ETS (auctioning; with/no centralized revenue collection • levy/tax (with/no centralized revenue collection)

Administrative costs for sector

Table 37 – Administrative costs for ship owners/operators

	Explanation of score levels	Measure ranking
++	Lowest expected administrative costs	• standard & penalty scheme • levy/tax (with/no centralized revenue collection) • feebate scheme
+	Relative low expected administrative costs	
0	Medium expected administrative costs	Baseline & credit scheme
-	Relative high expected administrative costs	Cap & trade ETS (free allowances)
--	Highest expected administrative costs	Cap & trade ETS (auctioning of allowances with/no centralized revenue collection)

Explanation: see Appendix E.3.2.

Certainty of compliance costs

Table 38 – Certainty of compliance costs

	Explanation of score levels	Measure ranking
++	Highest certainty (no price/exogenous price)	• standard & penalty scheme • levy/tax
+	Relative certain	Feebate scheme
0	Medium certainty	
-	Relative uncertain	
--	Highest uncertainty (endogenous price)	• cap & trade ETS • baseline & credit scheme

Potential major objectives

Table 39 – Potenital major objections not directly related to costs

	Explanation of score levels	Measure ranking
++		
+		
0		
-		
--	Measures with 'operational efficiency' as (potential) measure base	• baseline & credit scheme targeting ships' operational CO_2 efficiency • feebate scheme targeting ships' operational CO_2 efficiency • standard & penalty scheme targeting ships' operational CO_2 efficiency
	Measures the design of which relies on 'operational efficiency'	• cap & trade ETS (free allowances) • baseline & credit scheme targeting ships' CO_2 emissions

Explanations:

- The discussions at the IMO have shown that agreement on a metric for an operational efficiency indicator might be very difficult.
- When under a cap & trade emissions trading scheme allowances are issued for free, an allocation mode has to be determined. Grandfathering (issuing free allowances based on entities historical emissions) rewards late movers and is often discarded as allocation mode. Production/activity benchmarks (also applied in the EU ETS) are often proposed as allocation mode instead. The operational efficiency of ships is an the obvious metric in this context. Disagreement regarding the metric of an operational efficiency indicator has thus also the potential to hinder the implementation of a cap & trade emissions trading scheme with free allowances.

F Detailed description of CGE model methodology

Description of CGE model

CGE models are multi-market and multi-sector economic models of behavioral responses of individual producers and consumers to price, technology, or any other external factor changes within the limits of available labor, capital, and natural resource endowments (Dixon and Rimmer, 2002). CGE is a state-of-the-art approach to economic impact analysis, since it maintains the advantages of input-output analysis, i.e. highly disaggregated sectoral representation, full consideration of all inputs, economic interdependence, and overcomes nearly all its limitations (Rose, 1995). In contrast to input-output analysis, CGE models are non-linear, include behavioral component, account for substitution between inputs, and provide information on prices and markets. Finally, their ability to incorporate engineering data, microeconomic production activities, trade flows, and price changes make CGE models ideal for analyzing the direct and indirect economic impacts of energy and environmental policies.

GTAP methodology and structure

The production structure of the GTAP model combines factor (labor, capital, and land) and intermediate inputs using Leontief specification, which also includes the energy substitution nest. The energy nest with a constant elasticity of substitution (CES) is formed by joining the electricity and non-electricity commodities, as well as non-electricity group. Then, the model combines energy sub-product with capital to produce the capital-energy sub-product. Next, the value added nest is generated by combining the capital-energy sub-product with other factors through a CES function. The final output is produced by joining the value added with intermediate inputs.

The household consumption in the GTAP model is generated by a constant-difference of elasticities (CDE) function. The household forms its preferences over consumption, savings and government spending using a Cobb-Douglas functional specification. Based on the CDE theory, the energy commodities with similar income and substitution parameters can be combined into one composite good, which will have the same parameters as the individual goods. Also, in the energy composite the substitution among energy commodities is described by a CES functional form.

Limitations of GTAP

The GTAP model has many strengths but also a few limitations, such as the assumption of equilibrium adjustments, perfect competition and perfect information. While these assumptions are unrealistic, their departure from reality is considered relatively small or unlikely to have a substantial effect on our results.

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