ENERGY EFFICIENCY AND ENVIRONMENTAL PERFORMANCE OF MARITIME LOGISTICS CHAINS: ESTIMATING THE CURRENT SITUATION – MAJOR CHALLENGES AND POSSIBLE PITFALLS

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ABSTRACT

A prerequisite for being able to identify and implement measures for global improvement of energy efficiency and environmental performance in a maritime logistics chain is a comprehensive and uniform way of calculating the greenhouse gas (GHG) emissions and energy consumption, the GEEC® of the chain. The main objective of this paper is to shed light on challenges and potential pitfalls involved in estimating the efficiency of maritime logistics chains, with special focus on energy consumption and CO_2 emissions, to be able to establish a benchmark against which the effects of improvement measures can be compared. The approach is based on both looking at the vessel in isolation and taking the maritime logistics chain, in which the vessel is an important link, as points of departure.

Keywords: Benchmark, energy efficiency, carbon emissions, supply chain, vessel.

INTRODUCTION

Anthropogenic emissions of greenhouse gases (GHG) are contributing to global warming, and global temperature increases exceeding 2°C above pre-industrial levels will likely lead to catastrophic global consequences (Walker and King, 2008). Due to this, the environmental consequences of intensifying international trade have gained importance. Since more than 80 % of the world trade (measured in tons) is performed by seagoing vessels, this discussion will also affect maritime transportation. International shipping is a significant contributor to global GHG emissions, responsible for approximately 3 % of global CO_2 emissions (Endresen et al., 2008; Buhaug et al., 2009; Dalsøren et al., 2009). Published scenarios for future shipping activities indicate a significant increase in emissions, unless regulations are imposed (Eyring et al., 2005; Dalsøren et al., 2006; Eide et al., 2009a; Buhaug et al., 2009; OECD, 2010). The International Maritime Organization (IMO) is currently working to establish GHG regulations for international shipping (IMO, 2009), and is under pressure, for example from the European Union (EU) and the United Nations Framework Convention on Climate Change (UNFCCC), to implement regulations with substantial impact on emissions (see, for example van Dender and Crist, 2008 and Gehring, 2008). Furthermore, even with regulations, reducing emissions below current levels will prove to be a challenge (Eide et al., 2009a). Other types of emissions from shipping, such as NOx and SOx, also impact the climate and human health (Fuglestvedt et al., 2009; Eyring et al., 2009; Winebrake et al., 2009; IMO, 2009; Lauer et al., 2009).

To be able to make qualified suggestions of the effects of introducing measures for improving the energy efficiency and environmental performance of alternative maritime transport systems or maritime logistics chains, accurate estimates, or benchmarks, of the current ('as-is') situation are a prerequisite. The reasons for discussing energy efficiency and environmental performance of maritime logistics chains and the challenges involved in estimating the "as-is" situation to be able to introduce the most efficient performance improvements can be summarized as follows:

- "Green pressure" on logistics chains is growing.
- Improving energy efficiency and reducing CO_2 emissions of shipping.
- Measuring and comparing energy consumption and environmental performance of alternative logistics chains and different transport modes is a complex process

The potential of improving energy efficiency and environmental performance in shipping

Although shipping is regarded as the most energy-efficient mode of transport, the potential for reducing emissions from this sector is regarded as significant (Berrefjord et al., 2008). The International Maritime Organization (IMO) ordered the IMO 2009 GHG study (Buhaug et al., 2009) as part of their work regarding climate change. As the core of the climate change debate is to limit the temperature increase to 2 degrees by keeping the CO_2 amount in the atmosphere below 450 ppm (IPPC, 2007), all emissions must be reduced and shipping emissions in 2050 must be less than half of today's level, given a constant demand for seaborne transport work. However, given future scenarios for growth in seaborne transport work, it is estimated that an 85% reduction in carbon emissions is required, from an average of 25 gram CO_2 per ton nm down to 4 gram CO_2 per ton nm (Buhaug et al, 2009). This will require introduction of novel measures in addition to the known as presented in Table 1.

Table 1. Potential reductions of CO2 emissions from shipping by using known technology and practices (Buhaug et al., 2009).

DESIGN (New ships)	**Saving of CO2/tonne-mile**	**Combined**	**Combined**
Concept, speed and capability	2% to 50%	10% to 50%	25% to 75%
Hull and superstructure	2% to 20%		
Power and propulsion systems	5% to 15%		
Low-carbon fuels	5% to 15 %		
Renewable energy	1% to 10%		
Exhaust gas CO2 reduction	0%		
OPERATION (All ships)			
Fleet management, logistics and incentives	5% to 50%	10% to 50%	
Voyage optimisation	1% to 10%		
Energy management	1% to 10%		

MEASURING AND COMPARING GEEC® IN TRANSPORT SYSTEMS

The ability to introduce the relevant measures to improve energy efficiency and environmental performance (GEEC®) in transport systems requires that the basis that is used to analyze and compare the effect of different measures is well understood and acknowledged. Since CO_2 is the main GHG it is natural to focus on CO_2 and for simplicity leave out the other emissions which anyhow will be calculated in a similar way to CO_2.

When calculating energy consumption and emissions in a logistic chain the results can be presented in two different ways: The energy consumption and emissions for the defined system regardless of volume transported, a system focus, for example emissions generated by one transport company. Alternatively, the energy consumption and emissions per unit of product going through the system can be calculated, a product focus.

With a focus on measuring the performance of a system with respect to energy consumption and emissions there is a need to know how effective a unit of product is moved within the defined system boundaries. The latter focus, the product focus, is therefore the one that is used in this paper. To be able to use a product focus one need to know:

- The energy consumption and emissions of the defined logistic system.
- The degree of utilization of the defined logistic system.

The unit used when presenting the environmental performance is CO_2 emitted per unit or ton of cargo or CO_2 emission related to the transport work carried out, i.e. CO_2 per ton-nm or ton-km. The general approach used when calculating the CO_2 per ton-nm or ton-km is:

a. Take the fuel used on the voyage and multiple it with the carbon content of the fuel and the result is the CO_2 emitted on that journey.

b. Take the cargo transported in tons and multiple with the distance resulting in the transport work performed in ton-nm or ton-km.

c. The CO_2 per ton-km is obtained by dividing the total CO_2 emitted on the transport by the transport work performed.

The above mentioned approach requires a good understanding of the degrees of utilization of the different modes of transport included in the calculations. In theory this should be straightforward, however questions arise. In previous research studies the carbon footprint and other emissions for the transport sector have been calculated basically using three different methods:

i. By using collected activity data and assume operational patterns and capacity utilization figures.

ii. By using the exact figures for the activity, operational pattern and capacity utilization (feasible at a company level).

iii. By using collected activity data, collected operational patterns and collected capacity utilization figures.

CHALLENGES IN ESTIMATING THE CURRENT SITUATION

To be able to make qualified suggestion about the effects of introducing measures in a maritime logistics chain and within sea transport for improving the GHG emission and energy consumption (GEEC®) of alternative chains, accurate estimates, or benchmarks, of the current situation are a prerequisite. There are two main approaches to performing such benchmarking studies. First, we can compare the performance of each link (nodes and legs) in the chain separately, e.g. individual means of transport, terminals, and warehouses. Secondly, we can look at larger parts or the whole of a logistics chain. Figure 1 illustrates the two approaches; the "vertical" approach, looking at one process, e.g. a single leg or node, and the "horizontal" approach, i.e. looking at the whole or a larger part of a logistics chain.

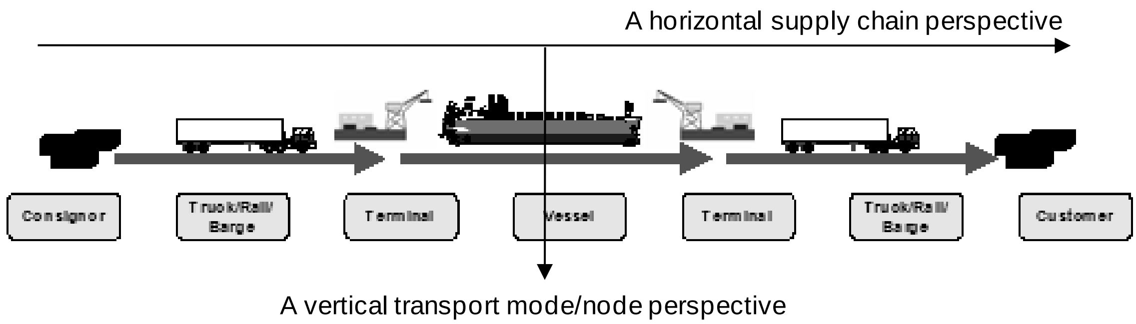

Figure 1. Two main approaches to benchmarking studies (Source: Authors).

Each of these two approaches has its challenges and possible pitfalls when estimating the "as-is", or benchmarks. However, the complexity of calculating energy consumption and CO_2 emissions increases when the focus is shifted from a single mean of transport or fleet of transport means to a total transport chain that includes terminal handling and warehousing or a total value chain that also includes production (Figure 2. Supply chain measurement complexity and potential impact). An extended focus and more complex assessment will enable a better position to suggest and analyse the effect of measures on the total energy consumption and environmental profile of the logistics chain as a whole. However, this come at the cost of increased complexity of the analysis and need for transparency in the analysis. The main reason for why a more complete analysis is sought is that such a focus will give a better position to shed light on whether changes that lead to improved GEEC anywhere in the logistics chain will lead to negative consequences for other parts of the chain, and reduce the effect of the measure or have a negative impact on the chain as a whole.

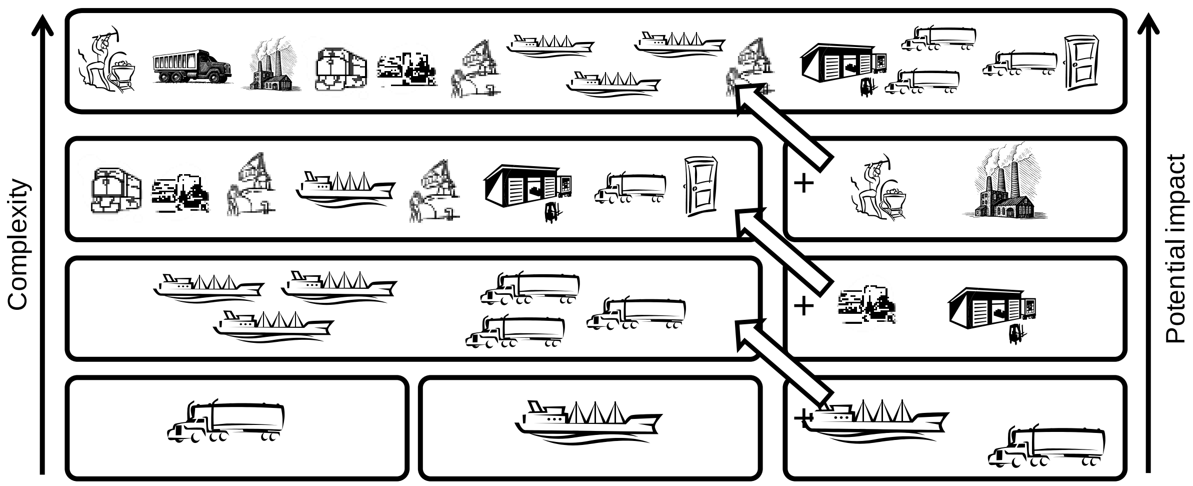

Figure 2. Supply chain measurement complexity and potential impact (Source: Authors).

A horizontal approach – The supply chain view

As mentioned in the introduction, by applying a "horizontal approach" we should be able to avoid or reduce the probability of introducing sub-optimal solutions, e.g. solutions that may be optimal when we look at one part of the chain in isolation, but that are negatively compensated for through changed behaviour or compensation in other parts of the chain.

The traditional focus when alternative logistics systems are compared has been on parameters like quality, speed, dependability, flexibility and cost. Forward, benchmarking of alternative logistics systems will increasingly include energy consumption and environmental performance due to the increasing green pressure on the supply chains. Environmental performance may comprise emissions to air and water, as well as external costs (cost for society, e.g. land use, noise, accidents). Our focus will be solely on GEEC® in the logistics chain. Activities related to the manufacturing process or the extraction of raw materials is not included in our discussion.

Several parameters need to be included in estimating CO_2 emissions by alternative logistics systems'. The main parameters to be included when analyzing different means of transport are:

- Technological characteristics: Type of fuel, size of engine (type and effect), vessel/vehicle capacity (payload), engine load and energy requirement under different operational conditions, fuel consumption under different operational conditions, means of emission reduction, and more.

- Operational characteristics: degree of utilization, round trip (loaded & ballast, repositioning, etc.), vessel/vehicle speed - average and range, specific engine load, specific fuel consumption/energy use, distance sailed/travelled, transport route (origin–destination matrix), and more.

- Support characteristics; does the system require other supporting systems, e.g. pilotage and/or tug assistance in port handling.

When analysing terminals and warehouses, we need to emphasize the following issues:

- All cargo handling must be taken into account.

- Waiting time and storage must be considered.

- Total energy use and emissions from warehouses/terminals under various operational conditions must be calculated.

- Energy use/emission related to the handling of one tonne/unit of cargo for a range of operational conditions should be estimated.

The following example illustrates the challenges that we are likely to face in our efforts to calculate CO_2 emissions from a logistics chain:

> A major European logistics operator wanted to calculate the carbon footprint of freighting a pallet on a truck from a terminal in Germany to a terminal in Spain, i.e. kg CO_2/pallet. The background for this requirement was that a competitor had published its own calculations on its website and had arrived at a result of 49 kg CO_2/pallet for the same operation. Our

> operator made his own calculations, which produced a result of approximately twice as much CO_2/pallet for the identical operation. How can we arrive at such different results for such a simple operation as transporting a single pallet on a truck over a relatively short distance, and what challenges would this sort of measurement problems likely bring?

The pallet mentioned in this example might well have originated somewhere else than the terminal in Germany and been destined for elsewhere than the terminal in Spain that was the system boundaries for this calculation. What would be the difference if we had been looking at the entire logistics chain and including a number of land and sea transport modes and interlinking nodes? If we extend the scope of the analysis, and then estimate the effects of improvement measures in the chain, the complexity will be further increased.

For the above example, the differences in the estimates could probably be traced back to one or more of the following main challenges and potential sources of error:

- Where do we set the system boundaries for what to include in the calculations?
- Which scopes of emission should be included?
- Is the physical unit of analysis uniformly defined?
- Are boundaries and interfaces between nodes and modes within the chain properly defined?
- Which methods are employed for making the calculations?
- What is the quality and availability of input data – mean figures, based on actual measurements of energy consumption, use of standardised GHG protocols (see e.g. the GHG Protocol Initiative, www.ghgprotocol.org), etc.?
- How to deal with shared logistics networks?

As can be seen from the above, the potential sources for making an error when calculating emission figures are extensive. The following section offers a brief outline of some of the main challenges and potential sources of error mentioned above.

Where do we set the system boundaries for what to include in the calculations?

As illustrated in Figure 2, the system boundaries can be defined in several different ways depending on the scope of study. The system boundaries can be defined as a single means of transport, a fleet of means of transport, a total transport chain, a total value chain, a total supply network and taking a life-cycle approach. The last few years the focus has been on giving unambiguous definitions of; what is the company measuring, what product, which part of the supply chain, and over what time period? In addition to these parameters there is now an increasing focus on “the breadth and depth of the measurement”:

- Breadth; direct and indirect energy, materials, capital goods.
- Depth; material extraction, transformation, distribution, use, disposal and recycling.

By moving the system boundaries to include a bigger part of the total system the complexity of doing the calculation and the potential sources of error will increase. One central question will arise when comparing two different logistics chains: How do we know that we compare two versions of a system with the same system boundaries, that the same units/sources of energy usage are taken into account and that these are treated in a uniform manner?

Which scope of emissions to include?

The concept of scope in a greenhouse gas context is based on the origin of the emission. The different scopes have been defined by the GHG protocol Initiative and can briefly be summarized as follows:

Scope 1: Direct GHG emissions
Direct GHG emissions occur from sources that are owned or controlled by the company, for example, emissions from combustion in owned or controlled boilers, furnaces, vehicles, etc.; emissions from chemical production in owned or controlled process equipment. Direct CO_2 emissions from the combustion of biomass shall not be included in scope 1 but reported separately. GHG emissions not covered by the Kyoto Protocol, e.g. CFCs, NOx, etc. shall not be included in scope 1 but may be reported separately.

Scope 2: Electricity indirect GHG emissions
Scope 2 accounts for GHG emissions from the generation of purchased electricity consumed by the company. Purchased electricity is defined as electricity that is purchased or otherwise brought into the organizational boundary of the company. Scope 2 emissions physically occur at the facility where electricity is generated.

Scope 3: Other indirect GHG emissions
Scope 3 is an optional reporting category that allows for the treatment of all other indirect emissions. Scope 3 emissions are a consequence of the activities of the company, but occur from sources not owned or controlled by the company. Some examples of scope 3 activities are extraction and production of purchased materials; transportation of purchased fuels; and use of sold products and services.

The more scope III emissions that can be mapped the more accurate will the final result be, but it will also make the calculation more complicated due to the increase of network emission sources that needs to be defined, mapped and calculated. Therefore, if scope III emissions is to be included in calculations, not only is access to meaningful and accurate data on these emissions needed, but also to define a way of identifying the most important scope III emissions to limit the boundaries of the supply chain, as well as defining the portion of the scope III emissions that should be allocated to the product or unit in question. A focus on scope I and II emissions would therefore be a sound point of departure for comparative studies. In cases where life cycles evaluation is an important part of the analysis, scope III should however be included.

Is the physical unit of analysis uniformly defined?

When doing the calculations it is important to include all main units and subunits of sources using energy that are included within the defined system boundaries. A source is defined as a non biologic unit within the defined scope that consumes energy or emits CO_2. We have the following main categories with some examples of units:

- Road: Trucks.
- Air: Airplanes; Pure cargo; Mix of cargo and passengers.
- Rail: Trains; Electric; Diesel; Mix of cargo and passengers; Pure cargo with switch in setup; Block trains; Switch locomotives.
- Sea: Dry bulk vessels; Wet bulk vessels; RoRo/RoPax vessels; Container vessels; Service vessels (e.g. PSVs, seismic); Commercial fishing vessels; Inland waterways vessels; Tug boats; Barges; Crew boats.
- Terminal: Cargo handling equipment; conveyors, cranes, forklifts yard tractors, pumps, motorized racks, other automated storage systems. Facilities; Environment control, air-conditioning, cooling plant, reefer plugs, lighting, computers and equipment, electricity used for office facilities.

It is also important that the unit which is the basis for the calculations is uniformly defined, e.g. what kind of pallet, which type of containers, which volume of bulk commodities, etc. is the point of departure for the calculations. Differences among the vast number of different units and sub-units that consume energy in a given system is a potential source of error when performing the calculation, if the units are not uniformly defined.

Are the boundaries and interfaces between nodes and modes within the chain properly defined?

A challenge with boundaries and interfaces is to be consistent with what is being added to each element meeting in the boundary/interface, to avoid that measures are neither double-counted nor forgotten. As a general rule energy consumptions and emissions should be allocated to the consuming entity. Some examples of potential conflict are:

- Cold ironing – When a berthed vessel uses electricity from land to run systems (cranes, HVAC, cooling, etc) this will generate less emission, but the reason for the ship being able to do this is that the port has invested in the infrastructure. I.e., the energy consumption and emissions from cold ironing should be allocated to the vessel.

- Truck idling – When a truck arrives at a terminal it is often depending on the terminal whether the truck can be serviced at once or if it has to idle (waiting while the motor is running) for a shorter or longer period of time (e.g. - to keep refrigeration going, prevent concrete from stiffening, keep the driver warm). If we follow the rule that the energy consumption and emission generated should be allocated to the consuming entity, this should be allocated to the truck.

- Port congestion – This can cause long waiting times outside of ports. Even though the reasons for the queue can vary, the energy consumption and emissions should be allocated to the vessel.

Which methods are employed for making the calculations?

It is of great importance that the methods used when calculating energy consumptions and emissions gives a reliable model to work with. There are two main factors that have to be in place to make sure we do not make conclusions on faulty grounds:

- The method has to be correct to the point that changes made to the model will result in the correct displacement of energy consumptions and emissions. If this is not correct we could end up with suggesting changes in the logistics system based on wrong assumption.

- The protocol data for different base units must be correct (for example energy consumption per ton/km for a certain vessel type or GHG emission per gram of marine diesel oil, MDO). If these numbers are incorrect we might still reach the correct conclusions based on a delta analysis, but we risk ending up with incorrect assumptions and modality shifts as a consequence of a poorly weighted model.

Most of the existing methodologies are created with the purposes of doing either a life cycle assessment (LCA) or to facilitate for an emission inventory for a business/area (the same methodology can be used for both). Often these methodologies have too little focus on base protocol data, or they have little-to-no connection between the different nodes and modes in the supply chain system, making them unfit for analyzing the result of parameter changes in the chain.

As an example of methodological requirements the following could be considered
different needs of methodologies looking at calculating the energy consumption and emissions of a logistics chain and a methodology developed to facilitate for a GHG inventory, consider the following; when creating a GHG inventory, emissions are reported into the inventory after they have occurred, most commonly based on actual fuel bills. This requires good reporting systems based upon proper accountant rules, over the fuel consumption. When evaluating different logistics solutions there might be a need to work with data for models instead of data from actual emissions. This requires that the protocol data and the methodology chosen have ability to transfer the effect of changing parameters. Figure 3 shows an example of a methodology for calculating energy consumption and emissions for modes and nodes in a logistics system developed in the MARLEN project.

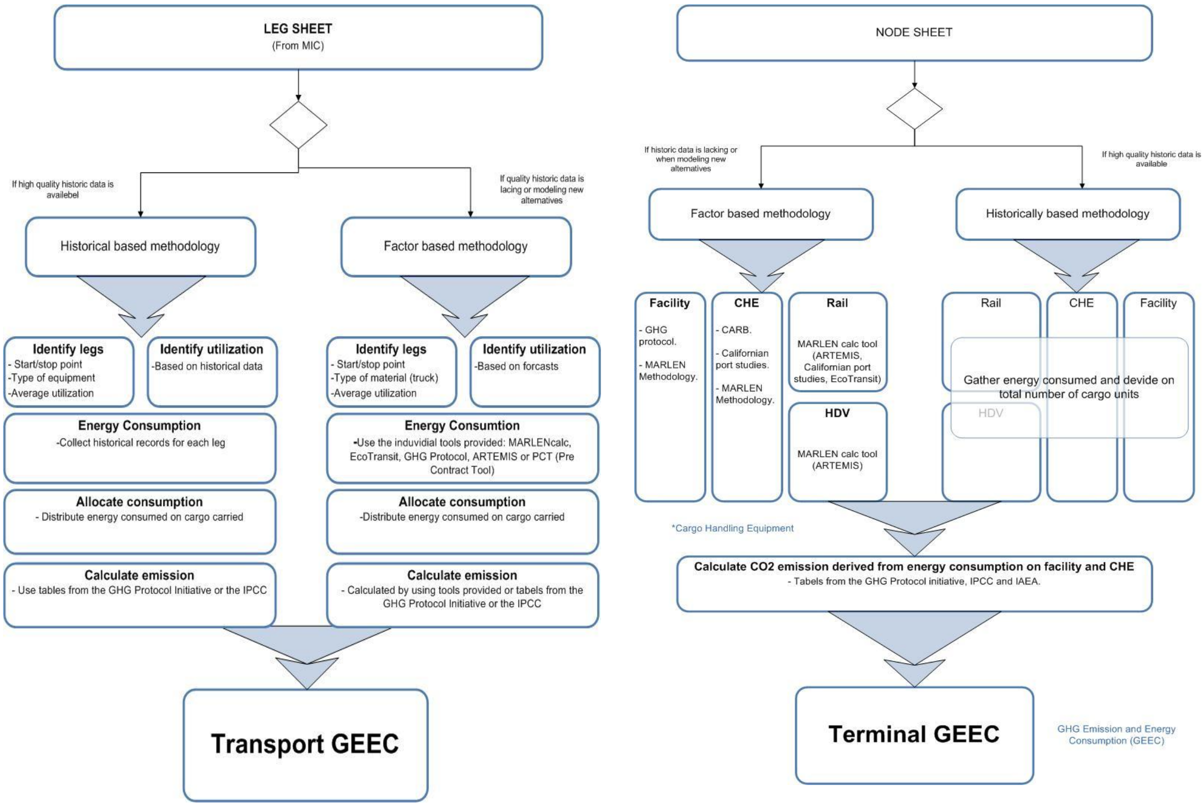

Figure 3.Methodological approach to GEEC calculation in nodes and modes (Source: Authors).

What is the quality and availability of input data?

When calculating energy consumptions and emissions several sources of data can be used. These can be divided into two main categories, historical based data and factor based data. The aim should be to always use the most accurate data source available. Historical based data can be gathered from the following sources:

- Fuel records (invoices, reporting systems, financial numbers).
- Electricity consumed (meters, invoices, financial reporting).
- Travelled distance (trip counters, reporting systems, contracts).
- Cargo handled (planning data, reporting data, invoices, financial reports, WMS systems).

Factor based data cannot be gathered, as this data needs to be modelled and documented in protocols. The models will mostly be used to estimate energy consumption. Handled cargo and travelled distances will be input from activity data (on re-routing of existing flow) or from contracts/industry actors (on new systems). When modelling, a set of factors for energy consumption are required, these factors can be collected from several sources. For both

approaches we need some common factors to convert fuel into energy and energy into emission. In cases where new systems have similar configuration to existing systems, activity data from the latter can be turned into factors and used in the modelling of the former. This great variety in data sources that might be used, data required and principals for converting fuel into energy and energy into emissions could be major sources for potential errors in carbon footprint calculations. An example of this is shown in
Figure 4, which shows a spread in CO2 emission per unit transport work for a range of vessels, as well as for road and rail transport. As can be seen from Figure 4 the spread in emissions for the fleet within each segment is considerable, even given the same calculation method, thus requiring specific knowledge about the system particulars to conduct a proper GEEC analysis, not only average segment properties.

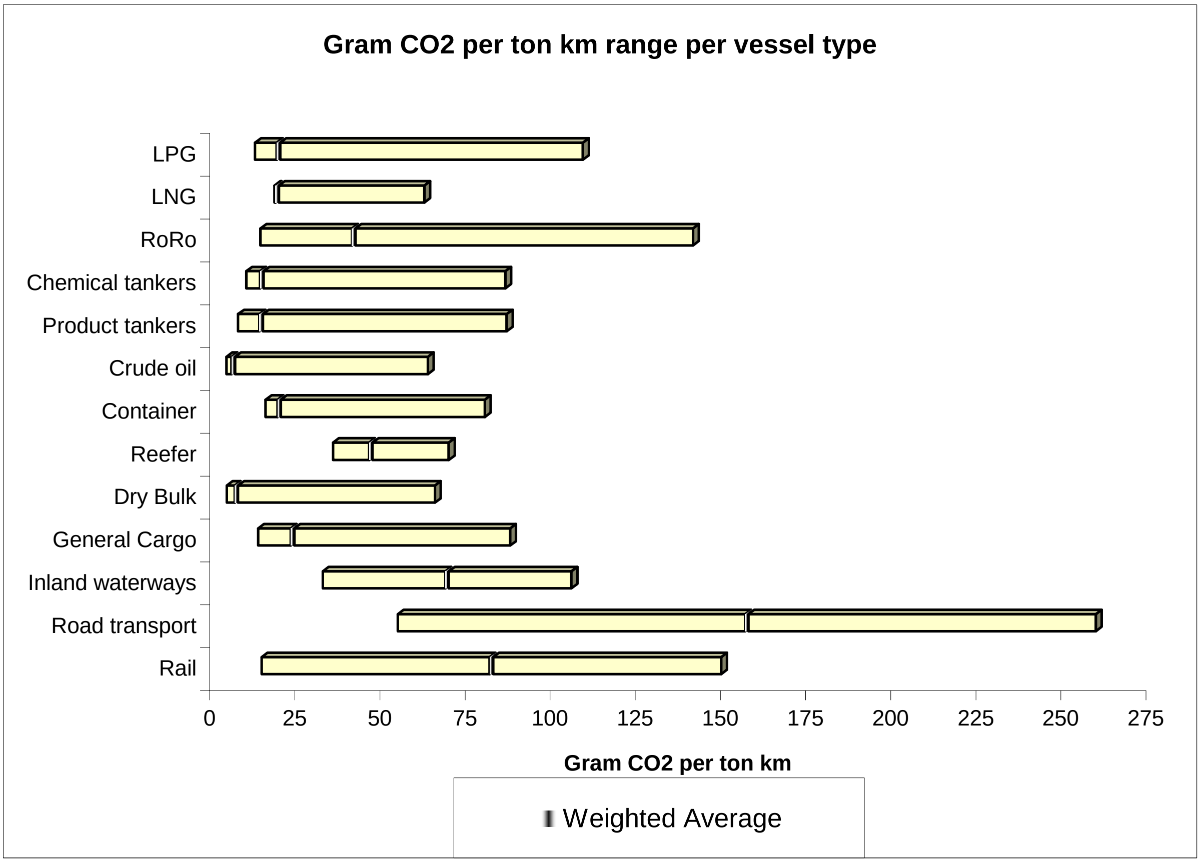

Figure 4: Variance in emission per ton km for a range of vessels and land transport (Source: Lindstad et al. 2009).

How to deal with shared logistics networks?

In a defined logistic system or supply chain there can be a variety of products and product owners using the same systems. This creates a need to allocate energy consumption and emission across different products and owners. Three scenarios where this could be relevant are:

<u>Different products/owners sharing transport unit</u>

In this scenario the allocation could be done by percentage of utilized capacity (time and cargo). The division in cargo capacity will be by weight or volume depending on what the limiting factor is. If both are limiting factors (90 % of volume is used by one product and 90 % of weight is used by another product and they together utilize 100 % of both weight and volume) the weight division should decide the allocation, since the weight is a stronger driving factor for increase/decrease in GEEC®.

It should also be taken into account that cargo will utilize different capacities for different parts of a period. So the allocated GEEC® from the cargo capacity utilization must therefore be multiplied with the percentage of time utilized on a defined period/leg. The calculation of cargo capacity to allocate GEEC® must allocate the GEEC® from the same time period; this is because different parts of a leg/period can have different GEEC® values. For instance: A truck is going from Rotterdam to Norway. Half of the truck's load capacity is used for automotive parts going to a location outside of Oslo, the other half of the capacity is office equipment to be distributed to 35 offices around Bergen. The distribution part of the latter leg will have a substantial higher GEEC® per km then the transport from Rotterdam to the factory outside of Oslo. Therefore, we cannot take the GEEC® for the entire trip and allocate it by cargo capacity and time capacity utilization; we need to break it up in smaller parts.

<u>Different products/owners sharing terminal</u>

Terminal activities have two GEEC® sources; cargo handling and facility. The facility GEEC® will be allocated by the same principle as in mobile units. The same also applies to cargo handling equipment, but it must be broken down to what cargo is handled by what equipment. For some equipment engine load must also be accounted for, for instance on pumps and conveyers.

<u>Retour to origin</u>

If a transport unit has to return to its origin empty, the GEEC® from the return leg must be allocated to the different cargo divided by the percentage of transport work (ton-km or volume-km) the cargo had on the trip. This could be complicated to allocate in complex logistic chains where a transport unit can have many different legs with a diversity of cargo, load utilizations and operating patterns. Three main logistic systems or scenarios with different challenges for calculating return-leg emissions is presented in Figure 5:

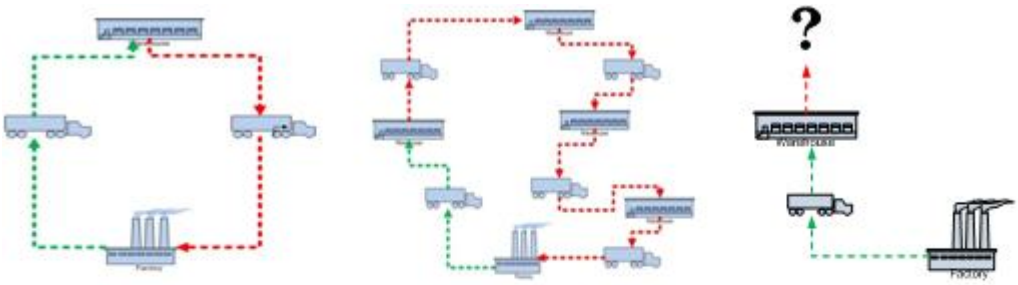

Figure 5. Three roundtrip scenarios: 'Pure' – 'Complex' – 'No return' (Source: Authors).

Pure roundtrip: In this scenario a truck will go straight to its destination and back again and all information about this trip is known. Knowing all the information a total emission for the round trip can be calculated and allocate to the transport unit, and from that allocate the correct amount to the cargo in question (the system could still have cargo from several owners).

Complex round trip: This is a situation where the truck will return to its origin via other transport nodes (e.g. terminals). This makes it harder to have an overview of the situation for the different transport legs. Furthermore it complicates the definition of a roundtrip.

No return trip: In this scenario there is only partial or no information on what the truck is doing after the destination terminal.

A vertical approach – A node/mode view: The vessel

While the focus in the previous chapter was on the supply chain, the focus in this chapter is on the vessel part of the chain and its operation. As has been illustrated above, the emission figures from shipping used today are both general and does not fully account for type and size of ships, the operational pattern, and so on. This introduces further sources of error when calculating energy consumption and emission in maritime logistics chains. In this chapter the broader chain perspective is left, and the focused challenge of estimating emissions from shipping as part of transport systems and logistics chains is discussed.

The maritime fleet consists of vessels where the same cargo can be transported on different vessels. The size of the vessels will for example vary from a few thousand tons up to hundred thousands of tons. The vessels may use different cargo handling technology, and have speed variations in the range of from 10 to 12 knots up to 25 to 30 knots. The choice among all these variants, that may be used in the same type of logistics chain will have an impact on the carbon footprint of the logistics chain. An example showing this could for instance be fertilizer. Fertilizers may be transported as:

- dry bulk with standard bulk carriers
- wet bulk in a tanker
- in big bags in open hatch vessels
- in a container on a container vessel (bagged or in a bulk container)
- on a trailer or a container on a Ro-Ro vessel (bagged or in a tank unit)

Examples of alternative supply chains for distribution of fertilizer are illustrated in Figure 6. As can be seen from Figure 6, it is not only the choice of vessel per se, but also the inter-linked cargo handling technology can impacts the resulting carbon footprint assessment. Due to this the system border for the vertical vessel approach, should also include the vessel specific cargo handling technology in the interface between the vessel and the terminal.

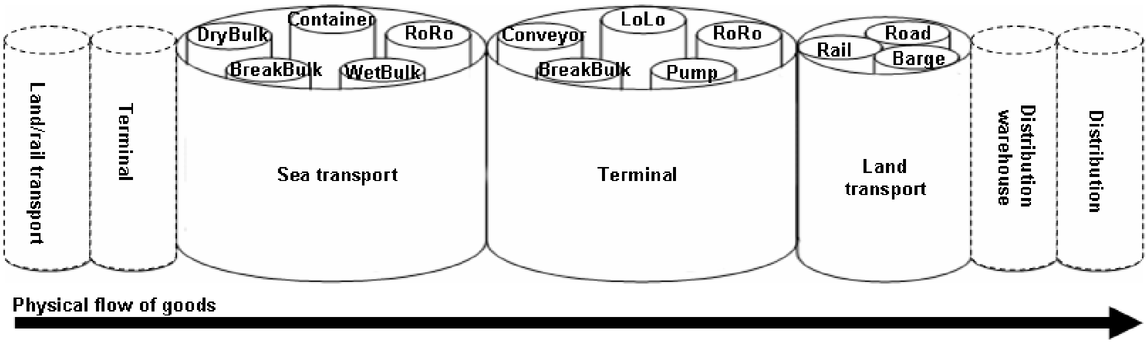

Figure 6. Alternative supply chains for distribution of fertilizer (Source: Authors).

Estimating seaborne transport work and its GEEC®

As introduced above, the maritime fleet consists of vessels where the same cargo can be transported on vessels with a big variance in size, speed and handling technology and where transport distances varies from a few nautical miles to more than 10 000. This impact the carbon footprint per unit transport work even for similar vessel types as presented in Figure 4. To handle this variety, models are needed. A typical approach has been to build a simplified model for each shipping segments and then use it as a basis for decision support regarding balance between supply and demand, contracts, fleet renewals. On the other hand researchers have built models where the primary focus is calculation of the total fuel consumption and energy efficiency. Examples of such research approaches are Corbet and Køhler (2003), Endresen et al. (2003), Kristensen (2007) and Psaraftis and Kontovas (2009).

The approach to more detailed figures for CO_2 emission from shipping as outlined below is based on a model simulating how different vessels types have been used in different trades and to gain knowledge about capacity versus demand. The model is based on a combination of exact and estimated data. The exact data is the world fleet as listed in the Lloyds Fairplay database which is divided into vessel type and size groups. For each vessel type the operational profile is established based upon studies of how vessels in each group are used and the cargo which they carry.

Trades and vessel alternatives

As the fertilizer example illustrated, it is a key issue that the model accommodate that a commodity can be transported by different vessel types and that some commodities can be either dry or liquid. All possible combinations of vessel types and cargo are marked with an 'x' in the matrix and when parentheses are added, '(x)', it means finished products only.

Table 2. Matrix of vessel / cargo alternatives (Source: Authors).

	Ship types									
Cargo type	**Dry bulk**	**Open hatch**	**Reef-er**	**Contain-er**	**Crude oil**	**OBO**	**Product/ chemical**	**RoRo**	**LNG**	**LPG**
Coal	**x**	**x**				**x**				
Iron ore	**x**	**x**				**x**				
Steel products	**x**	**x**		**x**				**X**		
Grain	**x**	**x**		**x**				**X**		
Cement & Clinker	**x**	**x**		**(x)**		**x**		**(x)**		
Fertilizer	**x**	**x**		**(x)**			**x**	**(x)**		
Aluminium	**x**	**x**		**(x)**						
Other dry bulk	**x**	**x**		**(x)**		**x**		**(x)**		
Crude oil					**x**	**x**				
LNG									**x**	
LPG				**x**				**x**		**X**
Clean petrol products				**x**			**x**	**x**		
Chemicals				**x**			**x**	**x**		
Veg oils				**x**			**x**	**x**		
Forest products		**x**		**x**				**x**		
Fruit and vegetables			**x**	**x**				**x**		
Frozen products			**x**	**x**				**x**		
FMC products		**x**		**x**				**x**		
Machines/equipment		**x**		**x**				**x**		
Project cargo		**x**						**x**		
Cars		**x**		**x**				**x**		
Trailers								**x**		
Trucks/heavy mach.								**x**		

A challenging part of building a model with this approach is to match the vessels with the cargo to replicate trade patterns. This is an iterative process since different vessel types and sizes partly transport the same cargo and partly their specifics. A core element is to establish the material flows and then match these ones with the vessel types which are used. Asbjørnslett et al. (2004) present a practical example of how material flow analyses are established.

Approaching the operational patterns and utilization for classes of vessels

There are several questions to be raised for a scheme as presented above, for example for the sea part of a maritime logistics chain; what is a voyage and is it correct only to express cargo as “tons transported”. When looking into voyage definitions, it becomes apparent that crude oil carriers will nearly always go one way with cargo and empty back, while both container carriers and Ro-Ro vessels will transport cargo both ways. The crude carrier will be loaded to utilize nearly 100 % of the dwt capacity one way and will return empty, while both the Ro-Ro and the container lines in general will have a 50 – 100 % utilization of the dwt capacity one way and 20 - 70 % utilization the other way. Based on these examples one may conclude that all calculations have to be roundtrip based and that all repositioning must be included to enable comparison between different sea going vessel types and between the transport modes. Regarding the way to express cargo, the amount in tons should always be the starting point. However, to enable comparisons both within the container and Ro-Ro segments and between them in addition to tons it might be relevant to use m^3, CEU's, trailers or TEU's when measuring the carbon footprint.

Understanding the operational patterns in different shipping segments is an important part of this approach and below the dry bulk trades are given as an example. The input from the analyses to the model is then structured as shown in Table 3.

Table 3. An example of operational patterns and utilization in the dry bulk segments (Source: Authors).

	No of ships	Dwt	Net pay-load capa-city	Dist-ance per voyage	Speed	Days per laden voyage	Cargo voy-ages	Ballast voy-ages	Dwt utili-zation per year	Cargo in million ton	Billion ton miles
Capesize 120'++	782	172.251	169.000	7500	14	33	6	5	52 %	769	5.769
Post P. 85'-120'	119	93.752	91.000	6500	14	29	7	5	55 %	74	478
Panamax 60'-85'	1.447	72.219	69.000	5500	14	28	8	5	56 %	759	4.173
Handymax 35'-60'	1.937	46.069	44.000	5000	14	25	9	5	58 %	729	3.643
Handysize 15'-35'	1.920	26.071	25.000	3000	14	16	15	7	59 %	648	1.944
Coastal 5-15'	464	9.318	8.600	1500	13	10	22	11	52 %	75	112
Small Bulk 0-5'	854	1.585	1.400	400	11	4	44	25	48 %	45	18
Total Dry Bulk	7.523	52.549			14	13	15	8		3.098	16.137

A further description of the vessel model

To give an overview of the more detailed level of the model, an example from the container segment 8.500 TEU+ vessel class is given. The information is given in Table 4, with an explanation of each column below.

Table 4. The vessel model, with a container segment example (Source: Authors).

	No of ships	Dwt	Net pay-load capa-city	Utili-sation when loaded	Dist-ance per voyage	Speed	Loading and unloading rates in Ton or	Theore-tical load and discharge times per	Additional port time and slow zones per voyage	Days per laden voyage	Cargo voy-ages	Ballast voy-ages
8500 TEU++	206	105 995	85 000	70 %	11000	25	200	4.6	4.0	31	11	0

	Dwt utili-zation per year	Engine size [kW]	Gram fuel per kWh	Fuel per ship in ton	Cargo in million ton	Fuel in million ton	Gram fuel per ton nm	Gram CO^2 per ton nm	Total CO_2 emission in million tonn	Days at sea with service speed	Days in port & slow zones	Days waiting, repair, crewlimits	Billion ton miles
8500 TEU++	56 %	67369	190	64281	135	13.2	9	28	42	251	94	19	1 483

Column by column the model contains:

- Vessel group; where the one used in the example are container vessels with a dwt capacity of 85 000 tons or more and a TEU - twenty feet equivalent capacity of 8500 container units and upwards.

- No of ships; there are 206 such vessel in the world fleet and the average deadweight (dwt) is 105 995 tons.

- Net payload capacity; is the dwt minus bunker, water, supplies and the empty weight of cargo containment units (empty weight of containers, mafi wagons and trailers).

- Utilization when loaded is related to the 'Cargo voyages' and the 'Ballast voyages' columns. In a container liner operation typical figures will be 90 % on the front haul (tour leg) and 50 % on the back haul (retour leg) which makes an average of 70 % as used in the model and there are no ballast legs. While a crude carrier operation will utilize the payload 100 % one way and go back empty and where the number of cargo legs will equal number of ballast legs.

- Distance per voyage; the distance one way for these vessels (as example from Japan to Europe) will typically be 11 000 nm. The distances used in the model for all vessel types and sizes are based on the typical trading patterns as a function of cargo and vessel types where the general rule is that the biggest vessels are used on the longest voyages.

- Speed; or actually the service speed is imported from the Lloyds Fairplay database and the value in this column is the average for each group.

- Loading and unloading rates in ton, TEU or lane meters per hour; is based on average values for the different vessel type and sizes.

- Load and discharge time per laden voyage; is the time purely used for loading and discharging while all times for approaching ports and other slow zones are included in the additional port time and slow zones per voyage.

- The days per laden voyage is then calculated based on the sailing time which is distance divided on speed plus all port time and slow zones. For ballast sailings the time usage is only the sailing since it includes no cargo handling.

- Dwt utilization per year; is a function of payload and its utilization on the cargo legs and the distances divided on dwt and the total sailed distance per year.

- The engine size (kWh); is imported from the Lloyds Fairplay database and the value in this column is the average for each group.

- The gram fuel per kWh; is set 10 – 15 % higher than the theoretical values to include auxiliary consumption and other losses due to inefficiencies.

- Fuel per ship in ton; is calculated based on the operational pattern of the vessel where the engine output is set to 90 % on the sailing legs and 30 % for all port and slow zones.

- Cargo in million ton; is calculated by multiplying payload * utilization * number of cargo voyages * number of vessels.

- Fuel in million ton; is given by annual fuel per vessel multiplied with number of vessels

- Gram fuel per ton nm; is calculated by dividing the billion ton miles for the vessel group (last column) on the fuel in million ton per vessel group

- Gram CO_2 per ton km; is calculated by multiplying the gram fuel per ton nm with the carbon factor in the fuel and divide on 1,852 to get it in km instead of nm to enable comparison across transport modes.

- Total CO_2 emission is million ton: is given by gram CO_2 per ton nm multiplied with total ton nm.

- The three columns; days at sea, days in port & slow zones and days waiting and repair shows how the 365 days per year is used in average in each vessel groups. For all the big vessels (like the 8500 TEU+ container vessels) the typical picture is a high number of days sailing at service speed out at sea with relative few port days while smaller vessels might spend more days in port & slow zones than out on the open sea.

- Billion ton nm; is the total yearly transport work in each group

A GEEC® overview of the dry bulk segments

Based on the above analysis structure a detailed calculation of emission factors can be derived for ship types and sizes. To give an overview of differences in GEEC® measures within a vessel segment,

Table 5 present an extract of the dry bulk vessel segment from the same scheme as the 8.500+ TEU segment of the container trade as presented above. We can see that there are considerable differences in GEEC® measures within the dry bulk segments. Access to emission figures at this level of detail will contribute significantly to the quality of the GEEC® calculations in maritime logistics chains.

Table 5. Examples of GEEC® measures on different dry bulk vessel segments (Source: Authors).

	# of ships	**Dwt**	**...**	**Gram fuel per kWh**	**...**	**Fuel in million ton**	**Gram fuel per ton-km**	**Gram CO_2 per ton-km**
Capesize 120'+	782	172251		190		13,0	2	4
Post p.max 85'-120'	119	93752		190		1,5	3	5
P.max 60'-85'	1447	72219		190		13,9	3	6
Handym. 35'-60'	1937	46069		190		15,3	4	7
Handysize 15'-35'	1920	26071		190		12,1	6	11
Coastal 5'-15'	464	9318		210		1,5	13	22
Small bulk 0-5'	854	1585		230		0,7	38	64
Total dry bulk	7523	52549				57,9	4	6

DISCUSSION

This paper has addressed some challenges and possible pitfalls that may arise when estimating energy efficiency and environmental performance (GEEC®) in maritime logistics chains. The following challenges and potential sources of error were defined:

- Where do we set the system boundaries for what to include in the calculations?
- Which scopes of emission should be included?
- Is the physical unit of analysis uniformly defined?
- Are boundaries and interfaces between nodes and modes within the chain properly defined?
- Which methods are employed for making the calculations?
- What is the quality and availability of input data – mean figures, based on actual measurements of energy consumption, use of standardised GHG protocols, etc.?
- How to deal with shared logistics networks?

Figure 7 shows a flow chart illustrating a sort of an easy to understand, step-by-step calculation of GEEC in maritime logistics chains. Such an approach supports the following quote:

> 'Shippers want standard emissions projections – reporting measurements is complicated enough without the added burden of choosing between schemes without knowing the risks involved and the full implication on doing so down the line' (Green Transport & Logistics World Summit, 2008).

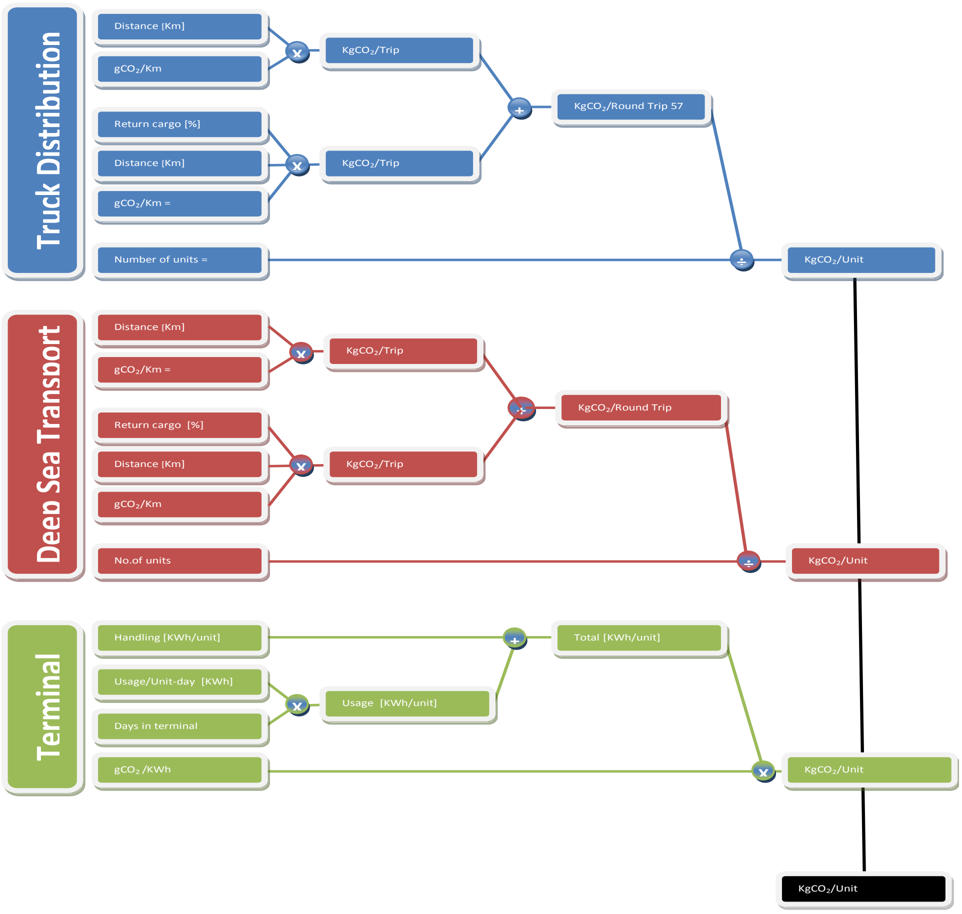

Figure 7. An example outline of a structured GEEC measurement approach.

A structured approach for the deep-sea transport in Figure 7 has been illustrated through the vessel model above. Even in such a structured set-up, there will be spreads within each segment as shown in Figure 4.

However, Figure 8 illustrates the main concern when performing these kinds of calculations. In establishing a step-by-step calculation, covering a chosen unit of analysis, from the single transport mean to a full supply network, requires proper definition and treatment of a wide range of challenging questions stretches into several dimensions, making up a multi-dimensional problem space. Such a multi-dimensional problem space is not the answer to the quote above, but comprise the challenges of calculating GEEC® in transport systems. As shown through the vessel model, this is a complex task, requiring a well documented basis for the analysis and comparison.

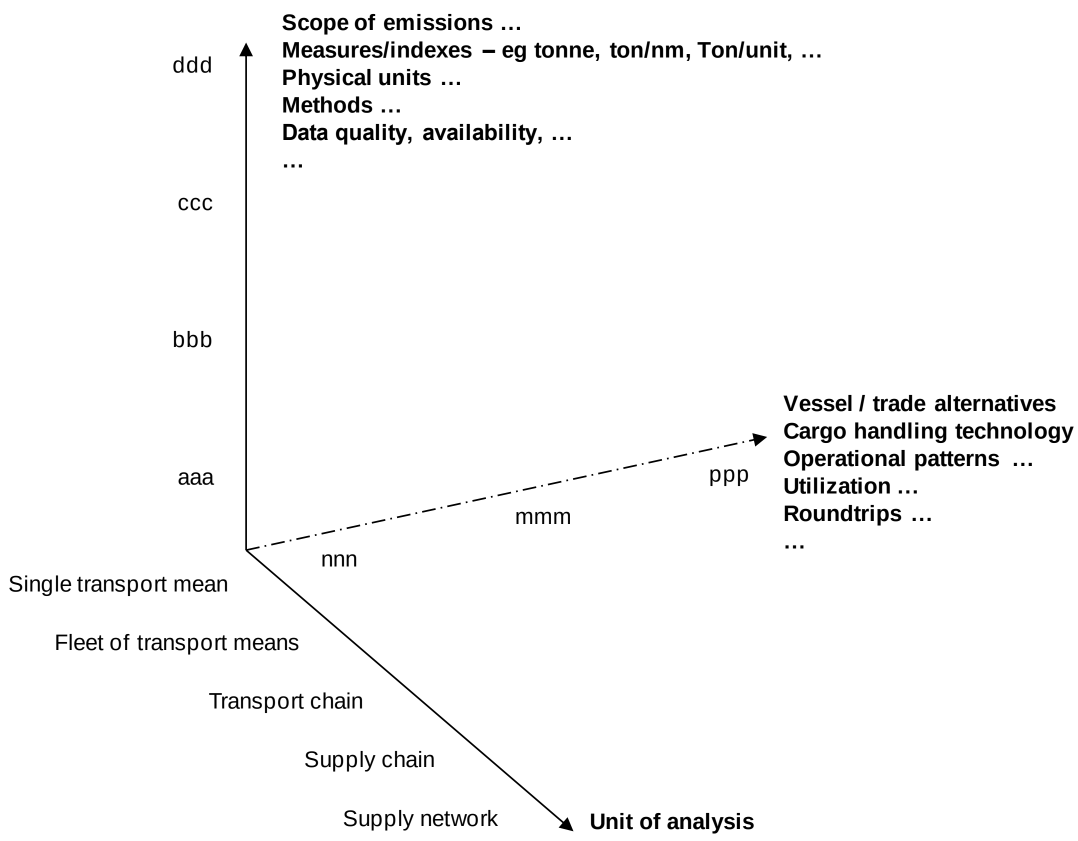

Figure 8. GEEC measurements with formal consideration of challenges and pitfalls.

This is the nature of the problem and this must be taken into account when trying to develop a more accurate and predictable methodology for calculation of GEEC® values. However, that should not be a hinder for trying to approach the establishment of a benchmark, against which the effects of further improvement measures can be analysed. As for most analyses, the objective is to find the relative differences, based on comparative set-ups between alternatives. Given that the alternatives are compared based upon the same approach; method, system boundaries, scope, ..., then the alternatives could act as benchmark on their own, and thereby overcoming the challenging part of comparing against a given, external benchmark without being fully certain that the basis of a given analysis is comparable with the basis of the benchmark. Above, this has been shown both for the shipping part, and discussed for the broader context of the door-to-door logistics chain.

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REFERENCES

Asbjørnslett, B.E., H. Lindstad and E. Uthaug (2004). The Dry Bulk Commodity Report. A Seachains, project report, MARINTEK, Trondheim.

Berrefjord, P.M., Endresen, Ø., Simonsen, B.C., Behrens, H., Alvik, S., (2008), "CO2 Emissions from Shipping – What Reductions are Achievable Through Technical and Operational Means", Det Norske Veritas (DNV) and Lloyds Register (LR) Submission to IMO MEPC58, Oslo, July, 2008.

Buhaug, Ø., Corbett, J.J., Endresen, Ø., Eyring, V., Faber, J., Hanayama, S., Lee, D.S., Lee, D., Lindstad, H., Markowska, A.Z., Mjelde, A., Nelissen, D., Nilsen, J., Pålsson, C., Winebrake, J.J., Wu, W.–Q.,Yoshida, K. (2009). Second IMO GHG study 2009, International Maritime Organization (IMO), London, UK, April 2009.

Dalsøren, S. B., Endresen Ø., Gravir G., Sørgård E., and Isaksen I. S. A. (2006). Environmental impacts of the expected increase in sea transportation, with particular focus on oil and gas scenarios for Norway and for Northwest Russian,112, Journal of Geophysical Research, D02310, doi: 10.1029/2005JD006927.

Dalsøren, S., Eide, M., Endresen, Ø., Mjelde, A., Gravir, G. and Isaksen, I. S. A. (2009). Update on emissions and environmental impacts from the international fleet. The contribution from major ship types and ports. Atmos. Chem. Phys., 9, 2171–2194.

Eide, M.S., Endresen, Ø., Skjong, R., Longva, T. and Alvik, S., (2009a). Cost-effectiveness assessment of CO2 reducing measures in shipping. Maritime Policy & Management, 36:4, 367 — 384.

Endresen, Ø., E. Sørgard, J. K. Sundet, S. B. Dalsøren, I. S. A. Isaksen, T. F. Berglen,and G.Gravir (2003). Emission from international sea transportation and environmental impact. Journal of Geophysical Research 108(D17) 4560.

Endresen, Ø., et al. (2008). The environmental impacts of increased international maritime shipping – Past trends and future perspectives. Study made for the OECD, DNV, Høvik.

Eyring, V. et al. (2009). Transport impacts on atmosphere and climate: Shipping, Atmospheric Environment (2009) page 1 – 37.

Eyring, V., Köhler, H.W., van Aardenne, J. and Lauer, A. (2005). Emissions from International Shipping: 1. The last 50 Years. Journal of Geophysical Research, 110.

Fuglestvedt, J.S., Shine, K.P., Berntsen, T., Cook, J., Lee, D.S., Stenke, A., Skeie, R.B., Velders, G.J.M., Waitz, I.A. (2009). Transport impacts on atmosphere and climate: Metrics. In Atmospheric Environment, pp. 1-30, Elsevier.

Gehring, M.W. (2008). Policy Instruments to Limit Negative Environmental Impacts from Increased International Transport: Constraints and Opportunities in International Law. . OECD/ITF Global Forum on Transport and Environment in a Globalizing World, 12-13 November 2008, Guadalajara, Mexico.

IMO (2009). International Shipping and Market Based Instruments 2009; International Maritime Organization (IMO) London, UK, November 2009; Anger, A.; Barker, T.; Pollitt, H.; Lindstad, H.; Lee, D.; Eyring, V.

IPCC. (2007). Climate Change 2007: Synthesis Report. Intergovernmental Panel on Climate Change, Valencia, Spain.

Kristensen, H.O. (2007). CO_2 Indexing Principles and Historical Development of Energy Efficiency of Ships. Report made for the Danish Sipowner Association. FORCE 107-27476/HOK/2007-10-31.

Lindstad H. and O.T. Mørkve (2009), A methodology to asses the Energy Efficiency and the Environmental Performance of maritime logistics chains. 10th International Marine Design Conference, May 26-29th 2009, Tapir Academic Press, Trondheim.

OECD (2010), Globalisation, Transport and the Environment, ISBN 978-92-64-07919-9.

Psaraftis, H.N. and C. Kontovas (2009), CO_2 Emission Statistics for the World Commercial Fleet. WMU Journal of Maritime affairs 2009, Vol.8, No.1, pp 1-25.

The Intergovernmental Panel on Climate Change. (u.d.). *Climate Change 2001: Working Group III: Mitigation. Appendix IV*. Hentet December 4, 2008 fra The Intergovernmental Panel on Climate Change: http://www.ipcc.ch/ipccreports/tar/wg3/477.htm

van Dender, K., Crist, P. (2008). Policy Instruments to Limit Negative Environmental Impacts from Increased International Transport – An Economic Perspective. OECD/ITF Global Forum on Transport and Environment in a Globalizing World, 12-13 November 2008, Guadalajara, Mexico.

Walker, G & King, D. (2008): The Hot Topic: How to tackle global warming and still keep the lights on. London: Bloomsbury.

Winebrake, J. J., J. J. Corbett, E. H. Green, A. Lauer, and V. Eyring, Mitigating the Health Impacts of Pollution from Ocean-going Shipping: An Assessment of Low-Sulfur Fuel Mandates, Environmental Science and Technology, accepted for publication, 2009.

Winther, M., Kousgaard, U. & Oxbøl, A. 2006: Calculation of odour emissions from aircraft engines at Copenhagen Airport. - Science of the Total Environment (366): 218-232.