Logistics-emissions tradeoffs in maritime transport

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Background

Drive for greener shipping:

- very high on IMO agenda
- very high on agendas of EU, individual coastal countries
- Reduction of ship emissions: top priority

Types of emissions

- Green House Gases-GHGs (mainly CO_2, but also CH_4 and others)
- Non-GHG (mainly SO_2, but also NO_x and others)

Kyoto Protocol

- United Nations Framework Convention on Climate Change -UNFCCC (1997)
- Urgent measures to reduce CO_2 emissions are necessary to curb the projected growth of GHGs worldwide.
- Shipping has thus far escaped being included in the Kyoto global emissions reduction target for CO_2 and other GHGs
- Some regulation exists for SO_2

Time of GHG non-regulation is rapidly approaching its end!

- Measures to curb future CO_2 growth are being sought with a high sense of urgency.
- As CO_2 is the most prevalent of these GHGs, any set of measures to reduce the latter should primarily focus on CO_2.
- Message of EC to IMO: Act now, or we shall act instead!

Measures contemplated

Technological

- More efficient (energy-saving) engines
- More efficient ship hulls
- More efficient propulsion
- “Cold ironing” in ports
- Cleaner fuels (low sulphur content)
- Alternative fuels (fuel cells, biofuels, etc)
- Devices to trap exhaust emissions (scrubbers, etc)

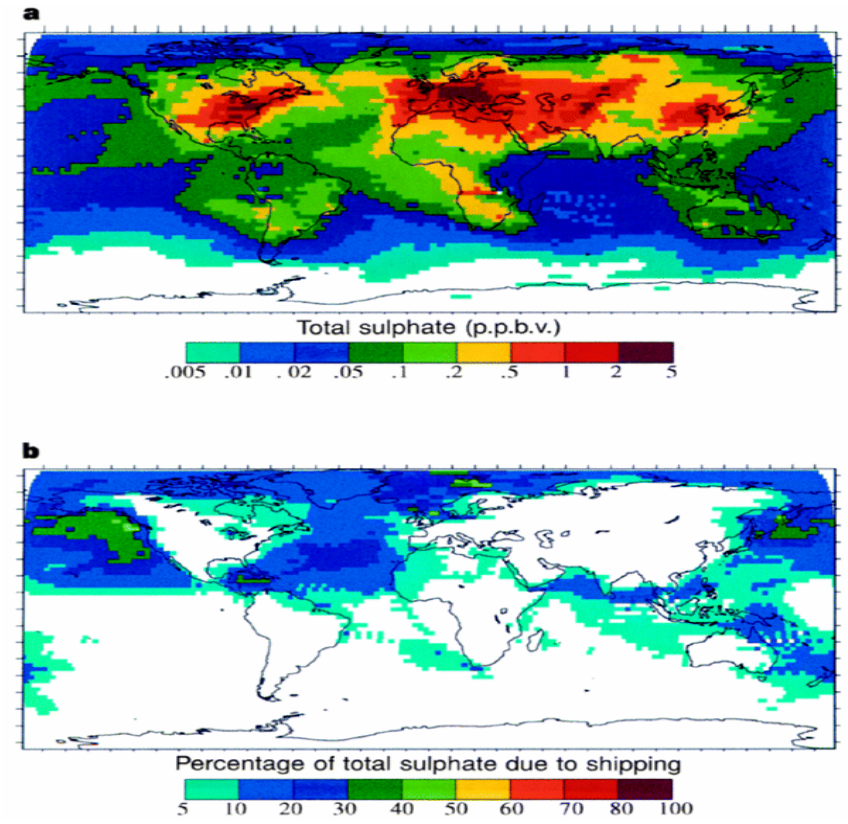
Operational

- Speed reduction
- Optimized routing
- Other, logistics-related (eg, fewer, bigger ships)
- Protected areas (SECAs)

State of the art

R&D and studies on:

- Estimation of emissions
- Impact of emissions on world climate
- Technological means to reduce emissions




SkySails
BELUGA PROJECTS

Remarks

- Even estimates of marine bunker sales are difficult to make
- Most global emissions estimates are based on modelling
- Not much on logistical dimension

Ship traffic densities (Endresen et al, 2003)

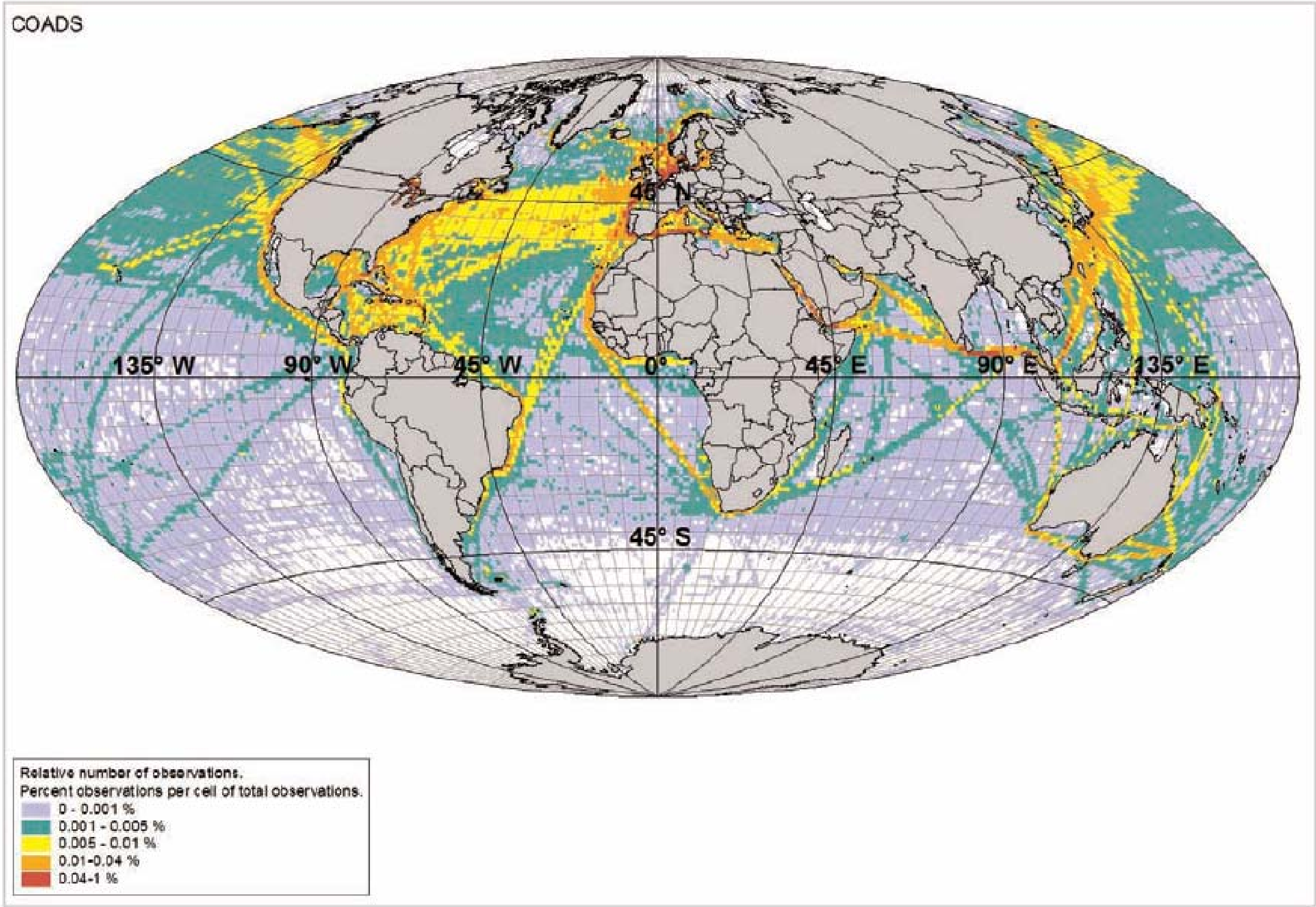
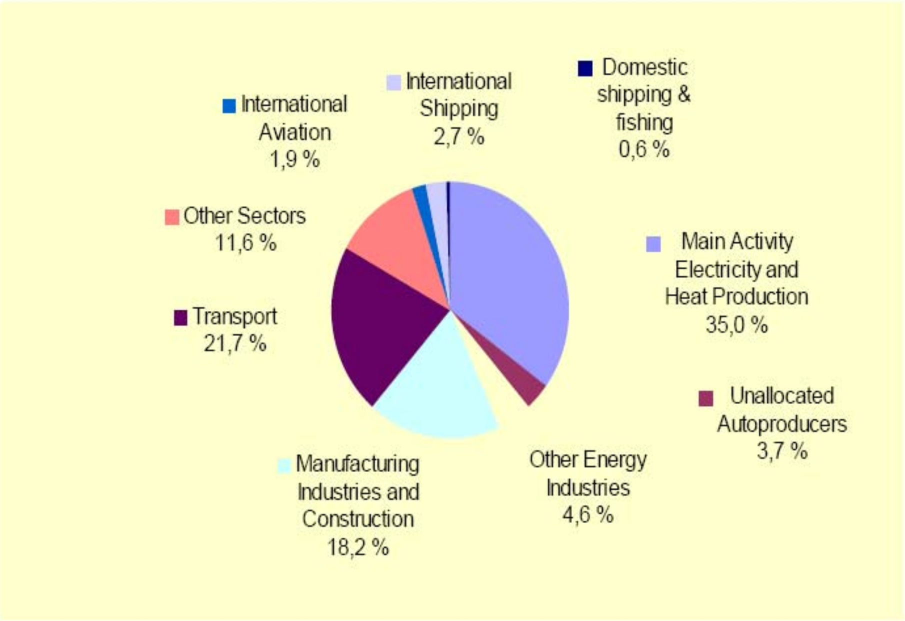


Figure 1. Vessel traffic densities for 1996 based on *COADS* [2001]. The integral over all grid cells equals 1.

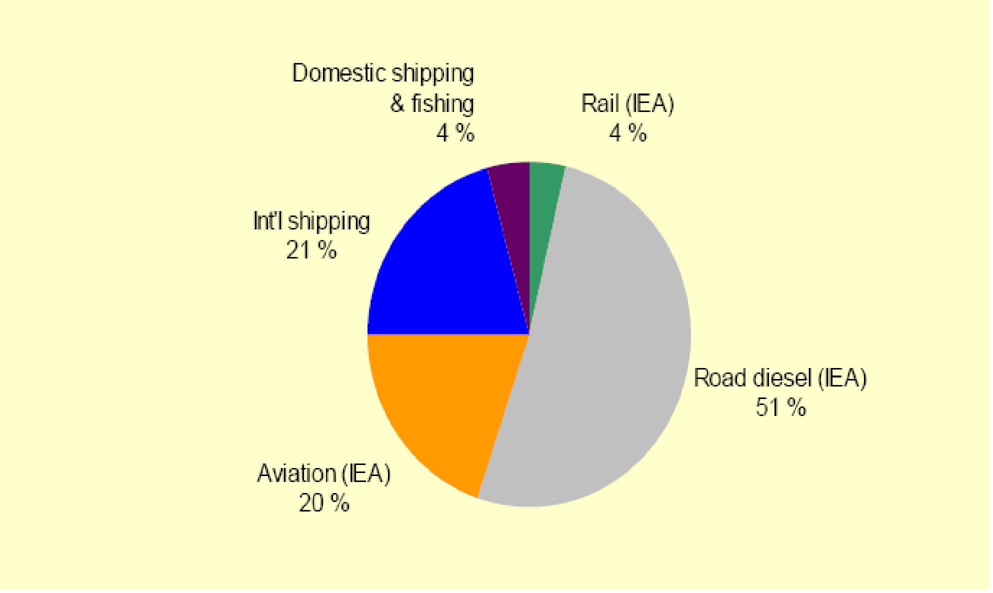
Share of global emissions



Data: International Shipping: This study. Other IEA. Reference year: 2005

MARINTEK SINTEF

Comparison with other modes (2005)



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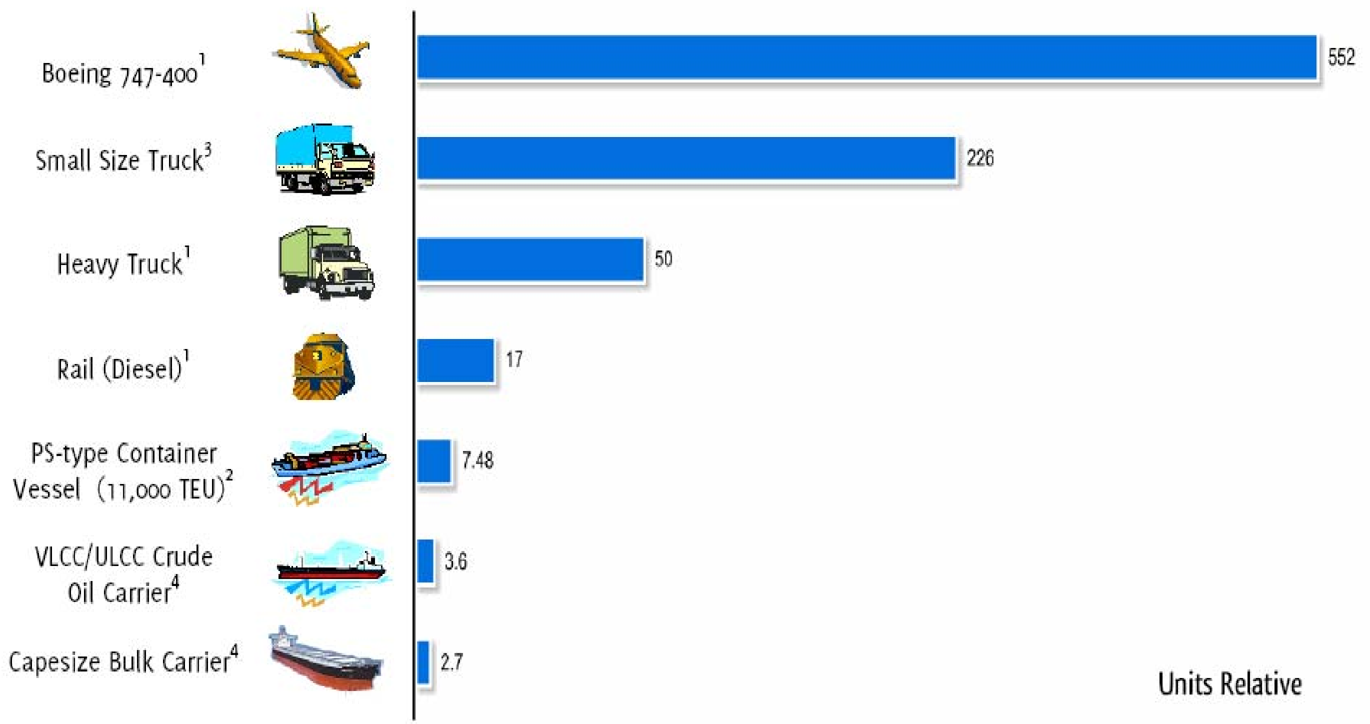
COMPARISON OF CO_2 EMISSIONS AMONG TRANSPORT MODES

(grams per tonne-kilometer)



Sources:

1. Swedish Network for Transport and the Environment (NTM)
2. Maersk Line
3. Man B&W Diesel
4. National Technical University of Athens (NTUA)

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NTUA Laboratory for Maritime Transport
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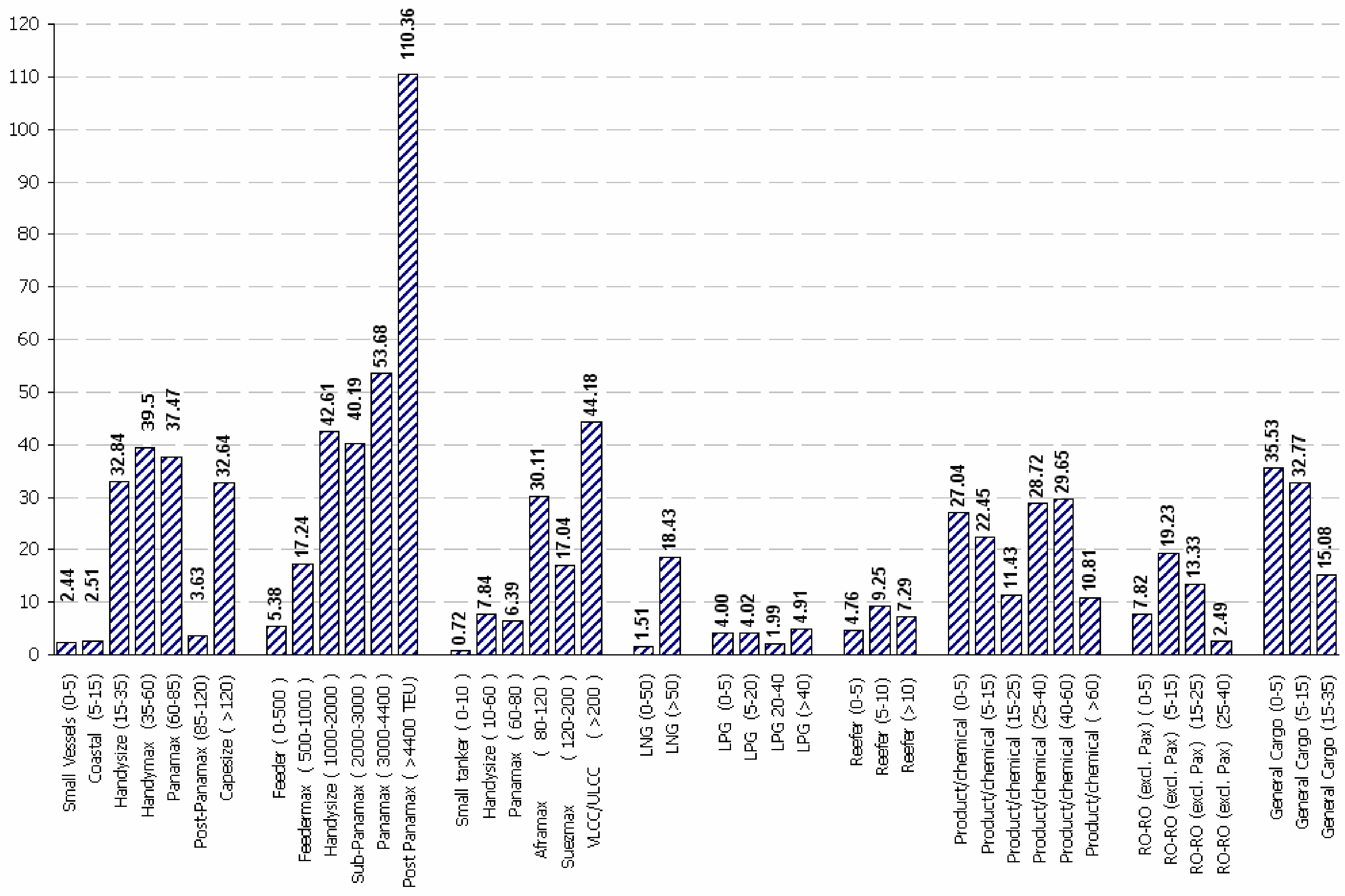
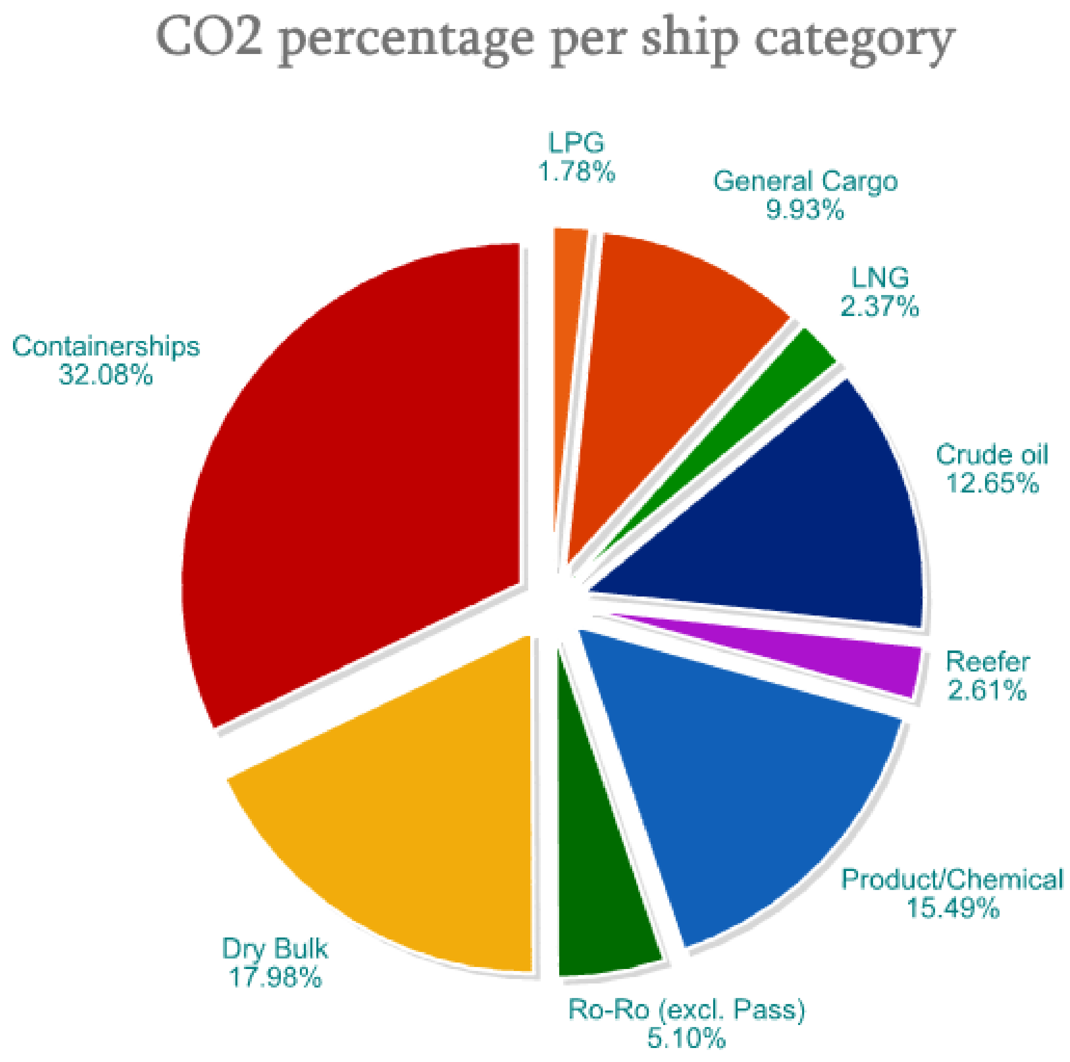
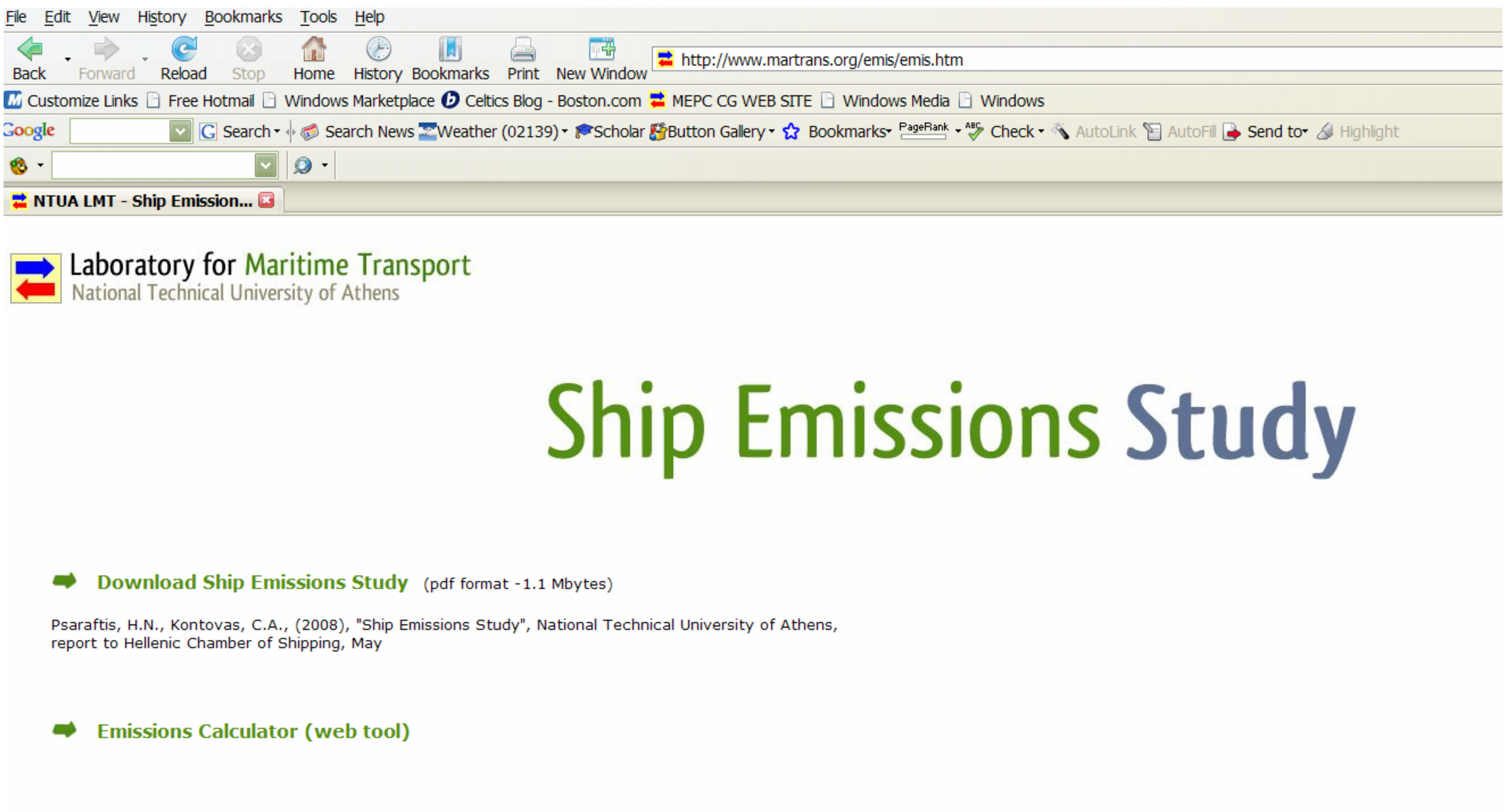
CO2 emissions per vessel category (million tonnes)




CO2 percentage per ship category
LPG
1.78%
General Cargo
9.93%
LNG
2.37%
Crude oil
12.65%
Reefer
2.61%
Product/Chemical
15.49%
Ro-Ro (excl. Pass)
5.10%
Dry Bulk
17.98%
Containerships
32.08%

NTUA ship emissions study

www.martrans.org/emis/emis.htm



Logistics trade-offs

- Reductions in emissions may have ramifications as regards the logistical supply chain
- Measures such as speed reduction or others will generally entail costs, such as in-transit inventory and others (eg, more ships to carry the same cargo).

Boomerang effect?

- Cleaner, low-sulphur fuel may make maritime transport (and in particular short-sea shipping) more expensive and induce shippers to use land-based alternatives (mainly road)
- That might increase overall GHG emissions!

Some basics

ONE tonne of marine bunker produces:

- 3.17 tonnes of CO_2 (indep. of fuel type, engine type)
- 0.02*S tonnes of SO_2, where S is the % of sulphur content in fuel ($0.5 \leq S \leq 4.5$)
- 0.057-0.087 tonnes of NO_x (engine-dependent)

Simple model

- Fleet of N identical ships, each of capacity (payload) W.
- Investigate impact of speed reduction
- Reduce speed, but add more ships to maintain same demand throughput

Fuel consumptions

- In port: f (tonnes per day)
- At sea: F (tonnes per day)
- Effect of speed change on fuel consumption: assumed cubic for same ship, ie

- $F_{new} / F = (V_{new} / V)^3$

Basic question

- If all ships reduce speed uniformly, and number of ships is increased to match demand throughput, does this lead to a lower fuel bill? (and hence to reduced emissions?)

- Answer: YES

Example

- L=20,000 km (~11,000 miles)
- V = 15 knots = 668 km/day.
- Port time= 3 days
- W= 100,000 tonnes
- N= 10 ships (identical)
- Operational days/yr= 355
- BUNKER PRICE = $600/tonne

Reduce speed by 1 knot (9.3%)

- From 668 to 624 km/day
- We would need 10.64 ships to satisfy same demand throughput per year
- Assume 11 ships (identical to original 10)

Net effect

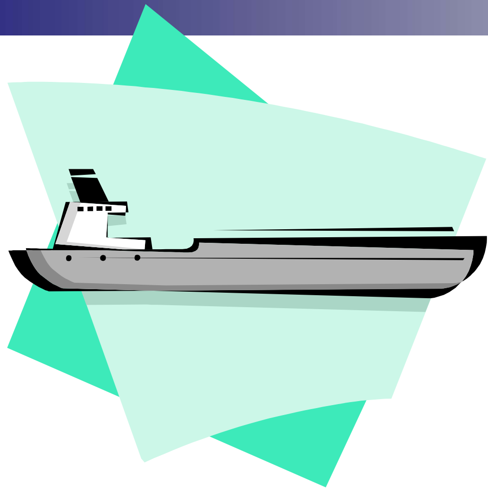
- Per ship FC reduces from 2,413 to 2,108 tonnes per round-trip (13%)
- TOTAL FLEET FC reduces from 130k to 117k tonnes per year (10%)
- TOTAL FLEET CO2 reduces from 412k to 372k tonnes per year (10%)
- TOTAL FUEL BILL savings: $7.56M/yr (10%)

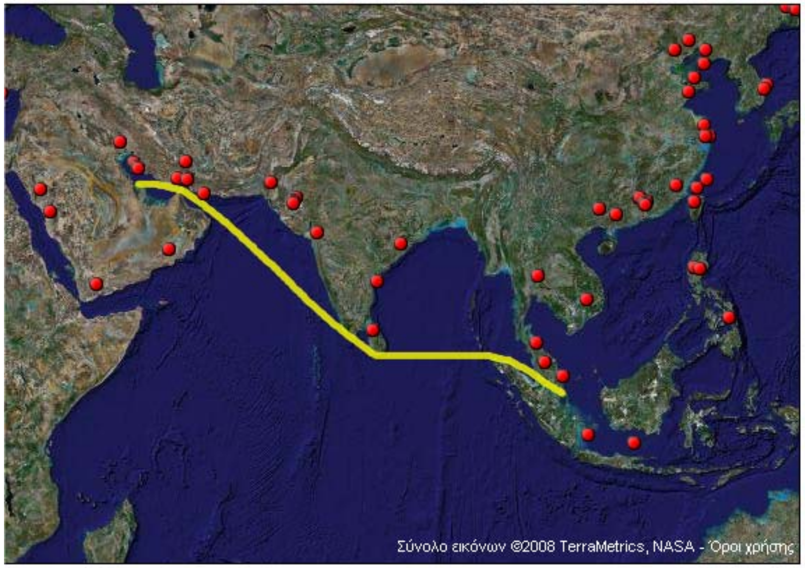
How many more ships needed?

- If speed V is reduced to v,
- $M = N(V-v)/v = NV/v-N = N(V/v-1)$

  Difference in fuel bills:

- = Const*pNV(V^2 -v^2) >0 always





VESSEL DETAILS

AFRAMAX TANKER
modern D/H - 106,000 DWT
Payload : 80,000

<u>Laden Leg</u>
Speed : 14.5 Kn
Consumption : 49 tn/day

<u>Ballast Leg</u>
Speed : 14.5 Kn
Consumption : 40 tn/day

<u>At port</u>
Consumption : 116 tn/day

ROUTE DETAILS

Ras Tanura – Singapore

Distance : 3,702 nm

<u>Voyage Time:</u>
Sea Time : 21.3 days
Port Time : 4.0 days

no canal transit time
no port waiting

Scenario:

One fleet of one ten (10) aframax tankers
12 trips per year (oper. Days = 303,6 days)

	Bunkers (tonnes)	Cost ($) 583.2 $/tonne	CO2 emissions emis. Factor 3.17
1 Aframax tanker - Per trip	1,410.78	822,766.90	4,472.17
Fleet of 10 ships	169,293.60	98,732,027.52	536,660.71

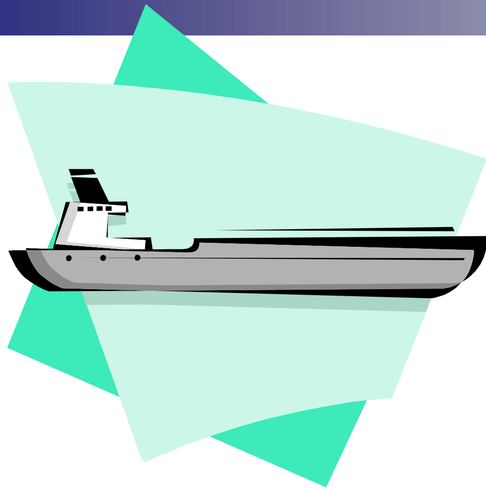
To satisfy the same demand i.e constant total payload within the same period of operation we need a number of additional ships. In this case we need 0,627 more ships thus we need one more ship.

For a fleet of 11 identical aframax vessels sailing with a reduced by 1 knot speed we obtain the following results :

	Bunkers (tonnes)	Cost ($) 583.2 $/tonne	CO2 emissions emis. Factor 3.17
1 Aframax tanker - Per trip	1,284.72	749.284.70	4,472.17
Fleet of 11 ships	159,607.57	93,083,133.11	505,955.99

We see that we have a reduction in fuel consumption and, thus, in CO2 emissions

NET REDUCTION	Bunkers (tonnes)	Cost ($) 583.2 $/tonne	CO2 emissions emis. Factor 3.17
	9,686.03	5,648,894.41	30,704.72



VESSEL DETAILS

PANAMAX BULK CARRIER (COAL)
modern D/H - 70,000 DWT
Payload : 66,000

<u>Laden Leg</u>
Speed : 13.5 Kn
Consumption : 32.5 tn/day

<u>Ballast Leg</u>
Speed : 14.0 Kn
Consumption : 30 tn/day

<u>At port</u>
Consumption : 2.5 tn/day HFO
1.0 tn/day DO

ROUTE DETAILS

Newcastle (AUS) – Japan
Distance : 4,287 nm

<u>Voyage Time:</u>
Sea Time : 26.0 days
Port Time : 4.0 days

no canal transit time
no port waiting

Scenario:

One fleet of one ten (10) Panamax bulk carriers

10 trips per year (oper. Days = 300 days)

	Bunkers (tonnes)	Cost ($)	CO2 emissions emis. Factor 3.17
1 BC - Per trip	826.79	484,622.73	2,620.92
Fleet of 10 ships	99,214.80	48,462,272.80	262,092.43

To satisfy the same demand i.e constant total payload within the same period of operation we need a number of additional ships. In this case we need 0,627 more ships thus we need one more ship.
For a fleet of 11 identical aframax vessels sailing with a reduced by 1 knot speed we obtain the following results :

	Bunkers (tonnes)	Cost ($)	CO2 emissions emis. Factor 3.17
1 BC - Per trip	712.45	417,939.64	2,258.47
Fleet of 11 ships	73,402.59	42,808,391.26	232,686.21

We see that we have a reduction in fuel consumption and, thus, in CO2 emissions

NET REDUCTION	Bunkers (tonnes)	Cost ($)	CO2 emissions emis. Factor 3.17
	25,812.21	15,053,680.10	81,824.70

However!

- STILL HAVE TO INCLUDE:
- Ship operational costs (other than fuel)
- Ship capital costs
- Cargo in-transit inventory costs

- So final answer depends on the above

Containership example

- String of N=100 (identical) container ships
- Payload W= 50,000 tonnes
- Base speed V= 21 knots
- Fuel Consumption at 21 knots = 115 tonnes/day
- Assume fuel price p= $600/tonne
- Fuel bill = $69,000/day/ship

- Reduced speed v= 20 knots
- FC at 20 knots = 100 tonnes/day (cube law vs. 21 knots)
- Fuel bill = $60,500/day/ship

For simplicity assume that

- These 100 ships go back and forth 2,100 miles full in one direction, empty in the other.
  - (if this is relaxed, analysis will be more involved, but will lead to similar results)
- Assume also zero loading and unloading times
  - (if non-zero, analysis will be more involved, but will lead to similar results).

AT FULL SPEED (case A)

- Transit time (one way) = 100 hrs = 4.17 days
- Round trip = 8.33 days
- Number of round trips per year (assuming 365 days operation): 43.8
- Tonnes carried each year (per ship): 43.8*50,000 = 2,190,000.
- Times 100 ships = 219,000,000.
- Total fuel burned/year/ship: 115 tonnes/day*365 = 41,975 tonnes
- Times 100 ships = 4,197,500 tonnes
- Total fuel cost (x$600) = $2,518,500,000.

AT REDUCED SPEED (case B)

- Transit time (one way) = 105 hrs = 4.375 days
- Round trip = 8.75 days
- Number of round trips per year (assuming 365 days operation): 41.714
- Tonnes carried each year (per ship): 41.714*50,000 = 2,085,714.

- To reach the previous figure of 219,000,000 tonnes of cargo, we will need 105 ships.
- Times 105 ships = 219,000,000 tonnes.
- Total fuel burned/year/ship: 100 tonnes/day*365 = 36,500 tonnes
- Times 105 ships = 3,832,500 tonnes
- Total fuel cost (x$600) = $2,299,500,000, **REDUCED**.

BENEFITS

- Reduction of CO_2 emissions: 3.17*(4,197,500-3,832,500)= 1,157,050 tonnes.
- Fuel cost difference = $219,000,000 for 5 more ships, ie, $43,800,000 per ship.
- If we can charter each of these ships for less than $120,000 a day, then case B is overall cheaper!

Cost to avert one tonne of CO_2

- BASIC QUESTION: HOW MUCH DOES IT COST TO AVERT ONE TONNE OF CO_2?

- Reducing speed saves fuel costs, BUT:
- If C (cost of chartering a ship) is high, it is conceivable that having more ships will cost more, even though total fuel bill is lower.

- Δ(cost) = NC(V/v-1) -365kpNV(V^2 -v^2)

ON A PER TONNE OF CO2 BASIS:

- **CATC = C/1,157kvV(V+v) –p/3.17 (p= price of fuel)**

CATC

- **CATC = C/1,157kvV(V+v) –p/3.17**

- Term {- p/3.17} is interesting.
- 1 tonne of fuel produces 3.17 tonnes of CO_2.
- Term is the cost of the amount of fuel not spent that would produce one tonne of CO_2.
- This amount would be saved if one tonne of CO_2 is averted.

In-transit inventory costs

- Hauling cargo at a reduced speed will entail additional in-transit inventory costs for the shippers.
- Such inventory cost is incurred during the time that the cargo is in transit, and is equal to a factor of t ($/tonne/day), times the transit time, times the amount of cargo.
- t is a function of the value of the cargo, interest rates, and other factors, value of time for the cargo, etc, and is assumed known.

Revised CATC

- **CATC =**

[C+182.5tW]/1,157kvV(V+v) - p/3.17

- The higher t is, the higher CATC is.

- No examples fully worked out yet.

Effect of bigger ships operating at slower speed

- Base scenario: Fleet of N ships and capacity W, operating at speed V.
- Alternate scenario: Fleet of M bigger ships, of capacity U (>W), operating at speed v (<V).
- Both fleets achieve same throughput per year:
  - $M=N(VW/vU)$

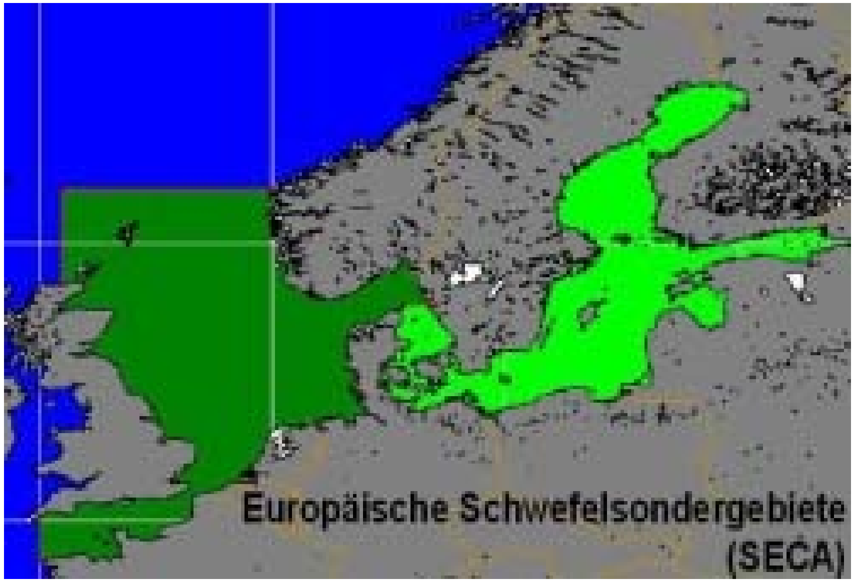
Basic result (M=N)

- **Substituting a string of ships with a string of bigger ships of same number, going at a slower speed so that total throughput remains the same, will reduce total fuel bill, hence total emissions.**

- Speculate result also holds for M<N.

Sulphur Emissions Control Areas: SECAs

- SO2 reduction: high on IMO agenda
- Regional policies
- Big question: how to limit SO2 emissions
- Various measures (cleaner fuel, scrubbers)



How about speed reduction?

- Can speed reduction at SECAs work, as a measure to reduce SO2 emissions?
- An easy question, for which the answer is not so easy.

Scenario

- A ship that goes from A to B, distance L.
- At beginning or end of trip, there is a SECA, of distance d (<L).

2 options:

- A. go all trip at a constant speed of V.
- B. reduce speed to v (<V) within SECA, but go at a higher speed of V* (>V) outside SECA, so that total transit time is the same.

Ratio of fuel consumptions

- Ratio R = FC(B)/FC(A) =

$=(L-d)^3/L(L-dV/v)^2 + (d/L)(v/V)^2$

- Can be shown that always R >1

Example

- L= 2000 nmiles
- d=200 (SECA)
- V= 20 (knots)
- v= 18 within SECA

- V* = 1800/(2000/20- 200/18)= 20.25 knots outside SECA.

- Then R = $(1800)^3/2000*(2000-200*20/18)^2 + (200/2000)\ (18/20)^2$

- = 0.9226 + 0.081 = 1.0036

This means that

- Speed reduction in SECAs will result in more total emissions (of all gases, including SO2) and more total fuel spent if speed is increased outside SECA to make up for lost time.
- The reduced emissions within the SECA will be more than offset by higher emissions outside (for all gases).
- The fuel bill will also be higher.

Use cleaner fuels in SECAs

- If a ship is forced to use low sulphur fuel at a SECA, to reduce SO2 emissions.
- This fuel is more expensive than high sulphur fuel. Hence freight rates go up.
- This may induce shippers to use land transport alternatives (trucking), which will increase CO2 emissions thru the logistics chain!

How to find out?

- Develop a model that examines these tradeoffs.
- Use the concept of generalized cost (taking into account value of time) and multinomial logit model to determine modal split.

PLANS

- Get more real data to make realistic examples for these models (in progress)
- Develop modal split model (in progress).
- Refine the models.
- Run various scenarios

Acknowledgment

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Thank you very much!

- www.martrans.org