

# Emission and Cost reductions in shipping through Economy of scale and Speed Differentiation

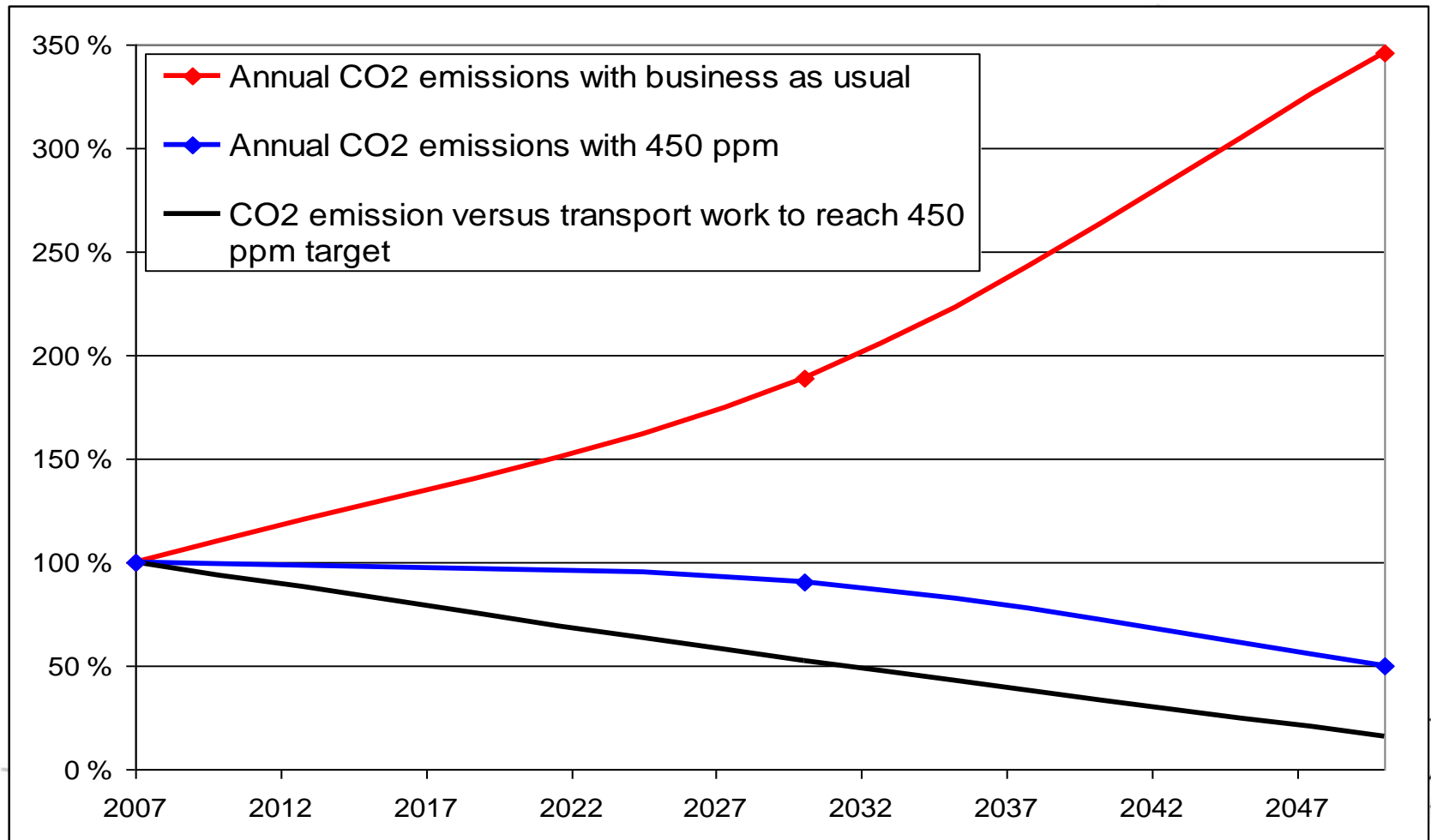
Haakon Lindstad

# Increase in World Energy usage from 1990 to 2007 and IEA 2030 scenarios

Source: World Energy Outlook 2009

	1990	2007	2030	
			Reference scenario	450 ppm scenario
Total Energy Demand	8 761	12 013	16 790	14 390
of which are renewables	1 124	1 515	2 376	3 159
Energy Related CO2 emissions	20 941	28 826	40 226	26 400
<b>Energy Sources</b>				
Coal, Gas & Oil (fossil fuel)	7 111	9 789	13 457	9 805
Nuclear	526	709	956	1 426
Hydro	184	265	402	487
Biomass and waste	904	1 176	1 604	1 952
Other Renewables	36	74	370	720
<b>Energy Usage</b>				
Power Generation (fossil fuel)	2 468	3 739	5 384	2 775
Industry	1 800	2 266	3 302	2 816
Transport	1 578	2 297	3 331	2 806
Other Sectors	2 440	2 941	3 830	5 051
Non Energy Use	475	770	942	942

# Emissions from shipping up to 2050 with Business as usual and with 450 ppm target



# Emissions to air – contribution from shipping

- More than 100 000 ships in world fleet. Carries more than 80% of international trade measured in metric tons (not in value)
- Shipping represents a significant contribution to the global anthropogenic emissions
  - 3% CO<sub>2</sub> (3.3% all shipping, 2.7% international shipping)
  - 4-9% SO<sub>2</sub>
  - 10-15% NO<sub>x</sub>

# Recent papers

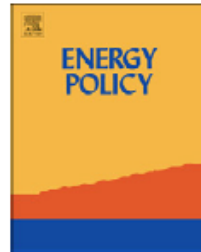
- Reductions in greenhouse gas emissions and cost by shipping at lower speed – Energy Policy Journal 39 - 2011
- The Importance of economies of scale for reductions in greenhouse gas emissions from shipping – Energy Policy Journal 46 – 2012
- Green Maritime Logistics and Sustainability – Contemporary Issues in Maritime Logistics (Emerald 2012)
- Comparing the costs and emissions of maritime and air transport – Under Review
- Assessment of profit, cost and emissions by varying speed as a function of sea conditions and freight market – To be submitted to Transportation Research Journal Part D



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## Energy Policy

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# The importance of economies of scale for reductions in greenhouse gas emissions from shipping

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Vessel type	Number of vessels	Average vessel size in dwt	Net payload capacity	Utilisation when loaded	Distance per voyage	Speed	Duration of cargo voyage	Number of cargo voyages	Duration of balast voyage	Number of balast voyages	Average engine size	Freight work	CO2 emitted
		ton										ton	nm
Dry bulk Capesize 120'+	782	172 000	169 000	97%	7 500	14	33	6	30	5	15 430	5 770	7
Dry Bulk 80-120'	119	94 000	92 000	97%	6 500	14	29	7	26	5	1 970	480	10
Dry Bulk Panamax 60 - 85'	1 447	72 000	71 000	95%	5 500	14	28	8	25	5	9 800	4 290	10
Dry Bulk Handymax 35 - 60	1 937	46 000	45 000	95%	5 000	14	25	9	22	5	8 210	3 730	13
Dry Bulk Handysize 15 - 35	1 920	26 000	25 000	90%	3 000	14	16	15	14	7	6 660	1 940	20
Dry Bulk coastal 0 - 15'	1 318	4 300	4 000	85%	787	12	6	36	5	20	1 950	130	91
General Cargo 15'+	1 215	25 000	24 000	90%	3 000	15	16	15	13	8	8 080	1 180	24
General Cargo 0 - 15'	16 065	3 100	2 800	85%	500	12	5	46	4	24	1 580	1 200	59
Container 8500 TEU +	206	106 000	85 000	70%	11 000	25	31	11	27	0	67 370	1 480	28
Container 5500 - 8500 TEU	175	80 000	64 000	70%	11 000	25	31	11	27	0	60 280	950	33
Container 3000 - 5500 TEU	1 068	55 000	44 000	70%	7 000	23	24	14	20	0	37 210	3 220	34
Container 2000 - 3000 TEU	789	33 000	27 000	70%	2 500	21	10	32	9	0	20 000	1 190	34
Container 1000 - 2000 TEU	832	21 000	16 400	70%	1 000	19	8	45	6	0	12 660	430	49
Container 0 - 1000 TEU	1 328	9 100	7 300	70%	650	17	6	49	5	0	6 230	220	80
Reefer 15'+	22	16 000	14 500	90%	4 000	21	14	16	12	10	14 970	20	61
Reefer 0 - 15'	1 204	5 200	4 700	90%	1 501	16	7	29	5	19	4 830	250	81
RoRo 35'+	20	45 000	36 000	70%	8 500	18	30	12	27	0	20 230	50	27
RoRo 15' - 35'	409	20 000	15 800	70%	1 800	19	11	33	9	0	14 170	260	54
RoRo 0 - 15'	1 981	4 200	3 400	70%	437	14	4	80	4	0	4 980	160	227
Crude oil 200'+	506	295 000	289 000	99%	9 000	15	42	4.5	37	4.5	24 830	5 860	7
Crude oil 120-200'	356	152 000	147 000	99%	6 000	15	29	6	26	6	17 160	1 990	10
Crude oil 75-120'	660	103 000	100 000	99%	2 500	15	16	12	14	12	12 730	1 880	15
Crude oil 15 -75'	410	52 000	50 000	98%	897	15	11	18	9	18	9 090	350	27
Crude oil 0-15'	121	3 600	3 500	98%	300	12	6	25	5	25	1 930	3	114
Products 75'+	47	112 000	108 000	85%	5 000	15	29	9	24	4	14 580	180	13
Products 15 - 75'	737	46 000	37 100	85%	3 637	15	23	10	20	5	8 960	1 030	24
Products 0 - 15'	4 122	2 500	2 100	85%	149	11	12	20	10	12	2 930	30	95
Chemical 40'+	533	48 000	45 000	85%	5 000	15	25	11	21	3	9 360	1 070	18
Chemical 15 - 40'	839	28 000	22 200	85%	2 897	15	21	12	18	4	7 820	710	33
Chemical 0 - 15'	2 496	4 900	4 000	85%	435	12	7	31	5	16	2 270	140	118
LNG 60'+	229	76 000	75 000	99%	8 000	20	31	6	27	6	27 090	820	33
LNG 15' - 60'	26	38 000	30 700	99%	3 923	18	21	10	18	10	14 910	30	47
LNG 0'-15'	10	8 600	8 200	99%	700	16	9	18	8	18	5 800	1	113
LPG 45'+	118	53 000	51 000	99%	5 000	17	21	9	18	9	13 400	270	22
LPG 15' - 45'	128	27 000	21 500	99%	2 031	16	13	15	11	15	10 060	100	39
LPG 0 - 15'	857	3 500	2 800	99%	320	13	5	34	4	34	2 550	40	172
<b>TOTAL</b>	<b>45 000</b>	<b>24 000</b>				<b>14</b>						<b>41 000</b>	<b>20</b>

## Key figures 2007

Vessel type	Freight work	No. Of vessels 2007 fleet	Average vessel size 2007 fleet	Average vessel size EOS fleet	No. of vessel EOS fleet	CO <sub>2</sub> emitted per freight unit 2007 fleet	CO <sub>2</sub> emitted per freight unit EOS fleet	Annual CO <sub>2</sub> emitted 2007 fleet	Annual CO <sub>2</sub> emitted EOS fleet
	billion ton miles		ton (dwt)	ton (dwt)		gram per ton nm	gram per ton nm	million ton	million ton
Dry Bulk	16 137	7 523	53 000	172 000	2 295	11.4	7.0	184	113
General Cargo	2 382	17 280	4 600	25 000	3 165	42.2	24.4	100	58
Reefer	258	1 226	5 400	16 100	412	84.8	65.3	22	17
Container	7 501	4 398	34 000	106 000	1 418	34.8	28.2	261	212
RoRo	485	2 410	7 200	45 000	388	75.8	25.7	37	12
Crude oil	10 061	2 053	143 000	295 000	994	9.7	7.0	98	70
Oil products	1 257	4 906	10 200	112 000	445	25.0	13.3	31	17
Chemicals	1 919	3 868	15 800	48 000	1 281	25.4	17.8	49	34
LNG	852	265	70 000	76 000	243	33.9	33.3	29	28
LPG	401	1 103	11 600	53 000	239	34.8	22.5	14	9
Sea River	16	1 169	1 136	7 466	178	31.3	11.5	3	1
<b>Total Freight</b>	<b>41 000</b>	<b>45 000</b>	<b>24 000</b>	<b>98 000</b>	<b>11 000</b>	<b>20.0</b>	<b>13.8</b>	<b>820</b>	<b>570</b>



## Key figures 2050

Vessel type	Freight work	No. Of vessels 2007 fleet	Average vessel size 2007 fleet	Average vessel size EOS fleet	No. of vessel EOS fleet	CO <sub>2</sub> emitted per freight unit 2007 fleet	CO <sub>2</sub> emitted per freight unit EOS fleet	Annual CO <sub>2</sub> emitted 2007 fleet	Annual CO <sub>2</sub> emitted EOS fleet
	billion ton miles		ton (dwt)	ton (dwt)		gram per ton nm	gram per ton nm	million ton	million ton
Dry Bulk	29 853	16 250	53 000	172 000	4 725	11.4	7.0	340	208
General Cargo	4 407	37 325	4 600	25 000	5 293	42.2	24.4	186	108
Reefer	477	2 648	5 400	16 100	706	84.8	65.3	40	31
Container	46 131	32 721	34 000	106 000	6 270	34.8	28.2	1 604	1 301
RoRo	897	5 206	7 200	45 000	403	75.8	25.7	68	23
Crude oil	18 613	4 434	143 000	295 000	1 875	9.7	7.0	181	130
Oil products	2 325	10 597	10 200	112 000	696	25.0	13.3	58	31
Chemicals	3 550	8 355	15 800	48 000	2 064	25.4	17.8	90	63
LNG	1 576	572	70 000	76 000	516	33.9	33.3	53	52
LPG	742	2 382	11 600	53 000	381	34.8	22.5	26	17
Sea River	30	2 163	1 136	7 466	329	31.3	11.5	6	2
<b>Total Freight</b>	<b>109 000</b>	<b>120 000</b>	<b>24 000</b>	<b>106 000</b>	<b>23 000</b>	<b>24.4</b>	<b>18.1</b>	<b>2 650</b>	<b>1 970</b>

Vessel type	2007 Freight work	Variable and fixed cost 2007 fleet based on new-buildings (1)	Variable and fixed cost 2007 fleet - (2)	Variable cost only 2007 fleet (3)	Variable and fixed cost EOS fleet	Total cost with 2007 new built fleet (1)	Total cost with 2007 existing fleet (2)	Total variable cost 2007 fleet (3)	Total cost in 2007 with EOS-fleet
	Billion ton nm	USD per million ton nm	USD per million ton nm	USD per million ton nm	USD per million ton nm	Million USD	Million USD	Million USD	Million USD
Dry Bulk	16 137	4 200	3 600	3 000	2 400	68 000	58 000	48 000	39 000
General Cargo	2 382	22 400	19 300	16 100	9 800	53 000	46 000	38 000	23 000
Reefer	258	28 400	25 500	22 500	19 200	7 000	7 000	6 000	5 000
Container	7 501	10 200	9 200	8 100	7 800	77 000	69 000	61 000	59 000
RoRo	485	36 400	30 000	23 500	13 900	18 000	15 000	11 000	7 000
Crude oil	10 061	3 500	3 000	2 500	2 500	35 000	30 000	25 000	25 000
Oil products	1 257	14 200	11 900	9 600	5 100	18 000	15 000	12 000	6 000
Chemicals	1 919	12 700	10 500	8 200	8 000	24 000	20 000	16 000	15 000
LNG	852	12 500	10 500	8 500	12 200	11 000	9 000	7 000	10 000
LPG	401	17 200	14 200	11 200	9 100	7 000	6 000	4 000	4 000
<b>Total Freight</b>	<b>41 000</b>					<b>318 000</b>	<b>275 000</b>	<b>228 000</b>	<b>193 000</b>
<b>Cost in USD per million ton nm</b>						<b>7 800</b>	<b>6 700</b>	<b>5 600</b>	<b>4 700</b>

## **Assessment of profit, cost and emissions by varying speed as a function of sea conditions and freight market**

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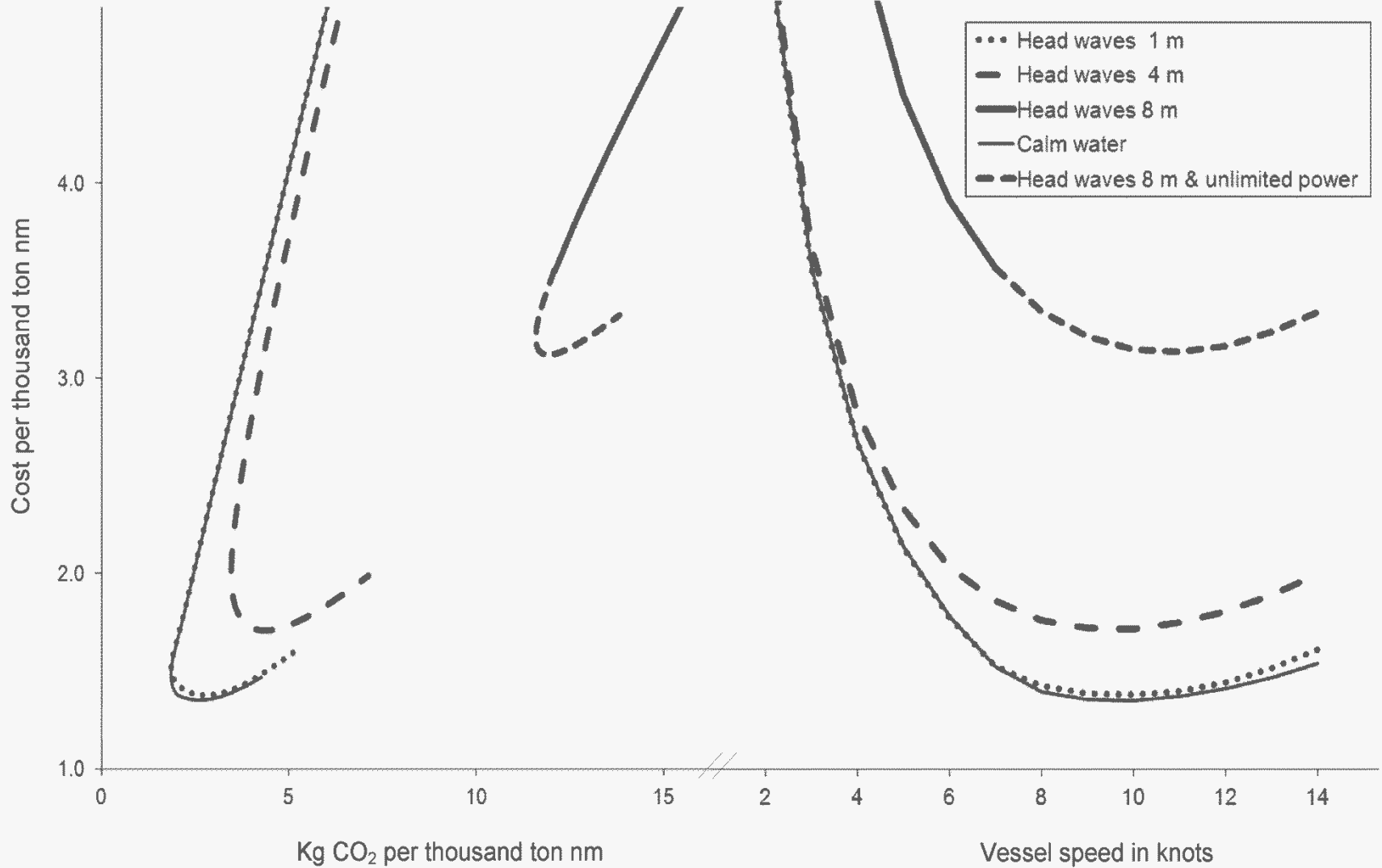
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Vessel type	Number of vessels	Average vessel size in dwt	Speed	Average engine size	Freight work	Total CO <sub>2</sub> emitted	Gram CO <sub>2</sub> per freight unit
		ton	knots	kW	billion ton nm	million ton	gram per ton nm
Bulk vessels above 15000 dwt	10 900	72 000	14.6	10 300	30 000	364	12
Container vessels	4 400	34 000	20.3	22 500	7 500	261	35
All other vessels	29 700	5 000	12.7	3 800	3 500	195	56
Total World Cargo fleet	45 000	24 000	13.9	5 000	41 000	820	20

# 1 – 8 meter head waves



Weather Profile	Design Speed	80 % of design speed	Profit Maximization	Cost Minimizing	Emission minimizing
Average Speed	13	11	12	10	8
Daily Income high TC <sub>c</sub>	49 800	39 300	45 500	36 900	26 800
Daily Income TC <sub>c</sub> ≈ cost	37 400	29 400	35 200	27 600	19 900
Daily Income low TC <sub>c</sub>	31 200	24 400	28 500	22 900	16 400
Cost per day	36 930	26 330	31 470	24 450	19 600
Profit per day high TC <sub>c</sub>	12 900	13 000	14 000	12 500	7 200
Profit per day TC <sub>c</sub> ≈ cost	500	3 100	3 700	3 200	300
Profit per day low TC <sub>c</sub>	-5 700	-1 900	-3 000	-1 600	-3 200
Average freight work in thousand ton nm per day with 50 % yearly utilization	11 122	8 871	10 208	8 373	6 210
Income per thousand ton nm with high TC <sub>c</sub>	4.48	4.43	4.46	4.41	4.32
Cost per thousand ton nm	3.32	2.97	3.08	2.92	3.16
Profit per thousand ton nm with high TC <sub>c</sub>	1.16	1.47	1.37	1.49	1.16
Cost reduction compared to design speed		11%	7%	12%	5%
CO <sub>2</sub> emissions in kg per thousand ton nm with 50% yearly utilization	10.7	7.4	8.8	6.8	5.1
CO <sub>2</sub> emission reduction compared to design speed		30%	17%	37%	52%

# Comparing the costs and emissions of maritime and air transport (under review)

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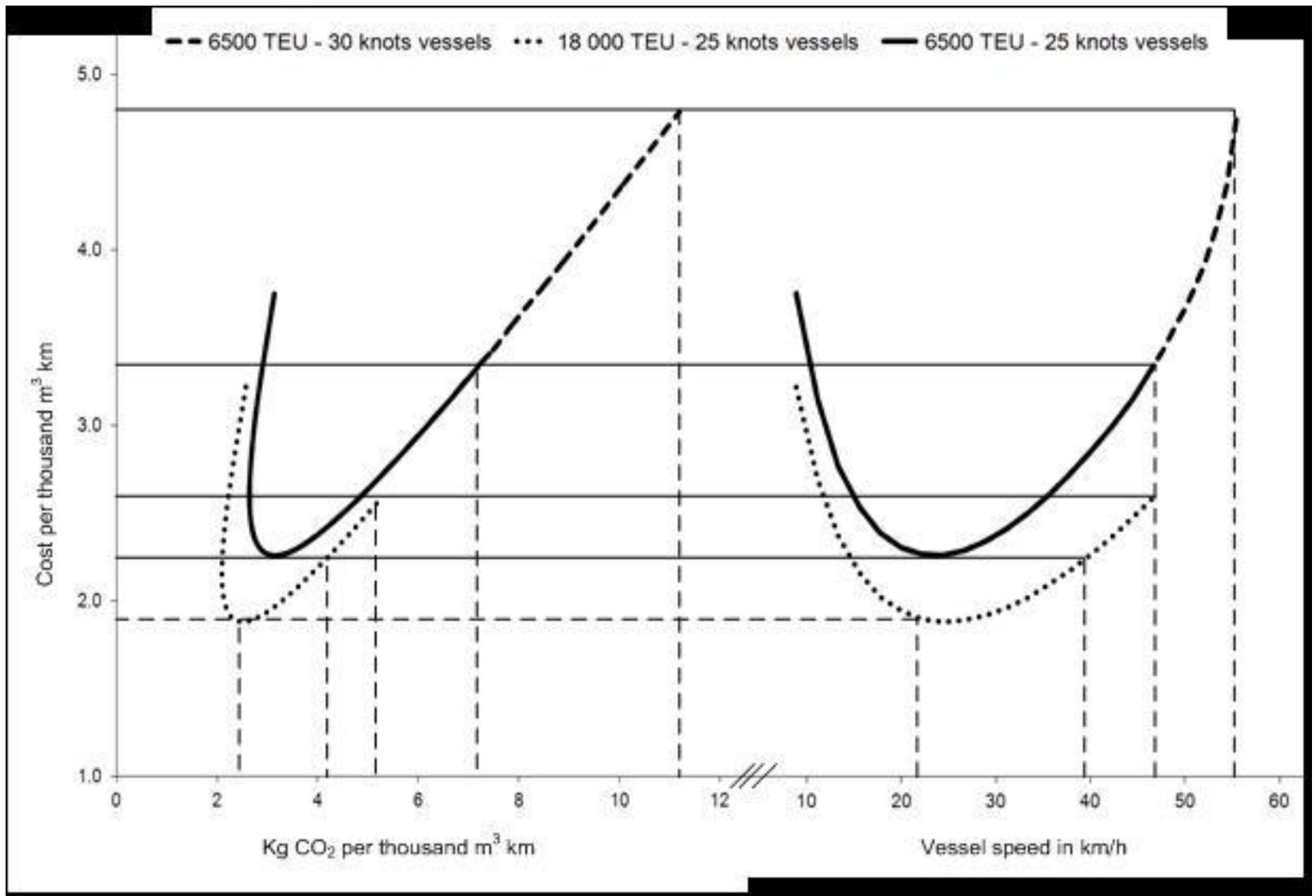
**Table 1: Key CargoLux figures (source: IATA and CargoLux)**

Daily key figures CargoLux		
Ton km produced per day	km/day	14 500 000
Fixed and operational costs of fleet	USD/day	1 800 000
Airport & flying fees	USD/day	700 000
Fuel cost (average price paid 750 USD/ton)	USD/day	1 800 000
Fuel consumption	ton/day	2 400
Cost per ton of fuel	USD/ton	1 000
Flight hours per plane per day	Hours	16
Number of planes		14
Average figures per flight CargoLux		
Ton cargo per flight	ton	47
Cubic metres per flight	m <sup>3</sup>	527
Cubic metre capacity per flight	m <sup>3</sup>	720
Specific gravity	kg/m <sup>3</sup>	90
Capacity utilization (based on cubic metres)	%	73%
CO <sub>2</sub> emissions per ton km	g/ton*km	517
CO <sub>2</sub> emissions per m <sup>3</sup> km	g/m <sup>3</sup> *km	47



***Table 2: Conversion factors and key figures for comparing air and sea freight***

		Air freight	Sea freight	Total
Freight work	billion ton nm		7 500	
Freight work	billion ton km	180	13 884	14 064
Conversion factor ton to m <sup>3</sup>		11.0	2.7	
Freight volume work	Billion m <sup>3</sup> km	1 980	37 487	39 467
Conversion factor for distance		1	0.5	
Adjusted Freight volume work	Billion m <sup>3</sup> km	1 980	18 743	20 723
Market share		10%	90%	100%



	Speed in km /h	Carriers	Distance in km	Freight time in days	CO <sub>2</sub> per thousand m <sup>3</sup> km distance adjusted	Freight volume in % of total	Total annual CO <sub>2</sub> emissions	Emission Reduction in %	Total cost in billion USD per year	Cost reduction in %
Unit	km/h		km	days	g/m <sup>3</sup> km	%	million tons	%	billion USD	%
AS IS										
Airfreight	850	747-Freighter	10 000	2.0	49.0	10%				
Container	46	6500 TEU	20 000	28.0	14.2	90%	366		230	
Lower speeds										
Airfreight	850	747-Freighter	10 000	2.0	49.0	11%				
Container	39	6500 TEU	20 000	31.5	11.4	89%	322	12%	216	6%
Economy of scale										
Airfreight	850	747-Freighter	10 000	2.0	49.0	11%				
Container	46	18 000 TEU	20 000	31.5	10.4	89%	304	17%	205	11%
Lower speeds&Economy of scale										
Airfreight	850	747-Freighter	10 000	2.0	49.0	12%				
Container	39	18 000 TEU	20 000	35.0	8.4	88%	275	25%	199	14%
Differentiated speeds&Economy of scale										
Airfreight	850	747-Freighter	10 000	2.0	49.0	10%				
Container	46	6500 TEU	20 000	28.0	14.2	20%				
Container	22	18 000 TEU	20 000	52.5	4.6	70%	227	38%	189	18%
Higher speeds&Economy of scale										
Airfreight	850	747-Freighter	10 000	2.0	49.0	8%				
Container	56	6500 TEU	20 000	21.0	22.0	22%				
Container	22	18 000 TEU	20 000	52.0	4.6	70%	248	32%	193	16%