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MARITIME

ALTERNATIVE HYBRID POWER-TRAINS

Dr. Elizabeth Lindstad, SINTEF Ocean AS

SAC MEETING 20-09-2018

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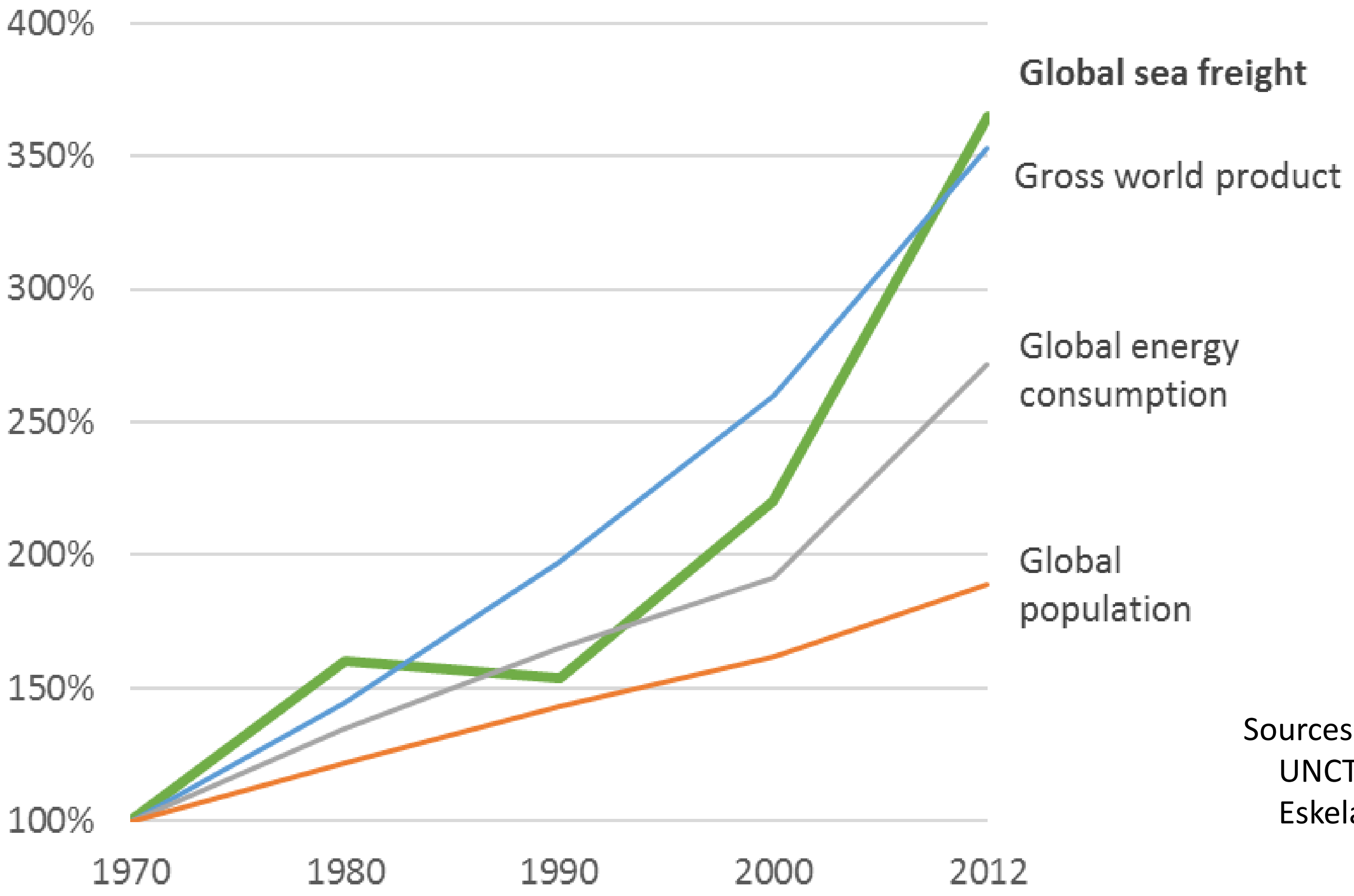
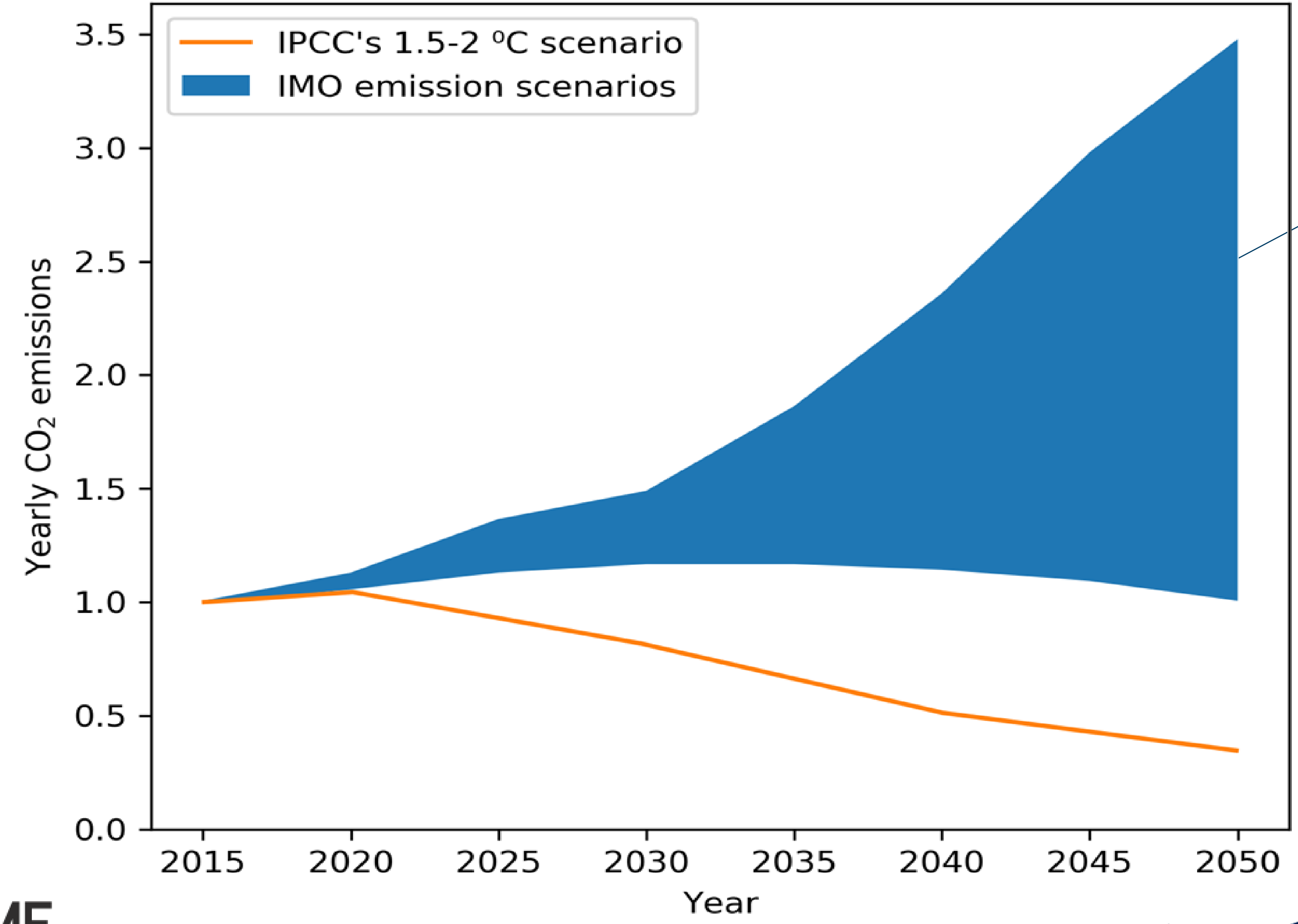
www.smartmaritime.no

Growth in global sea freight vs. GDP, energy, population



Sources:
UNCTAD (2014), IEA (2014), Lindstad (2013), Eskeland and Lindstad (2016)

Shipping emissions projections towards 2050



16 different scenarios developed by the Third IMO GHG study

Source:
Smith et al. (2014),
IPCC (2013)

IMO 50 % GHG reduction up to 2050 - Context

- From 1970 onwards annually:
  - 3 % freight growth;
  - 2 % increase in fuel consumption
  - 1 % efficiency improvement, mainly through larger vessels
- None of the third IMO GHG scenarios (2014) indicated a reduction, in best case stabilization
- Reaching the 2050 target will require:
  - 3 – 6 % annual efficiency improvements
- Measures to reach the 50% GHG reduction target

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Alternative scenarios for achieving 50% GHG reduction from shipping in 2050

1 – Low and zero carbon fuels	3 – Minimizing energy consumption: through ship design, power setups, size and operational speed
Combining Scenario 1 – 3	2 - Climate mitigation through cooling emissions at high seas & Offsetting through MBM

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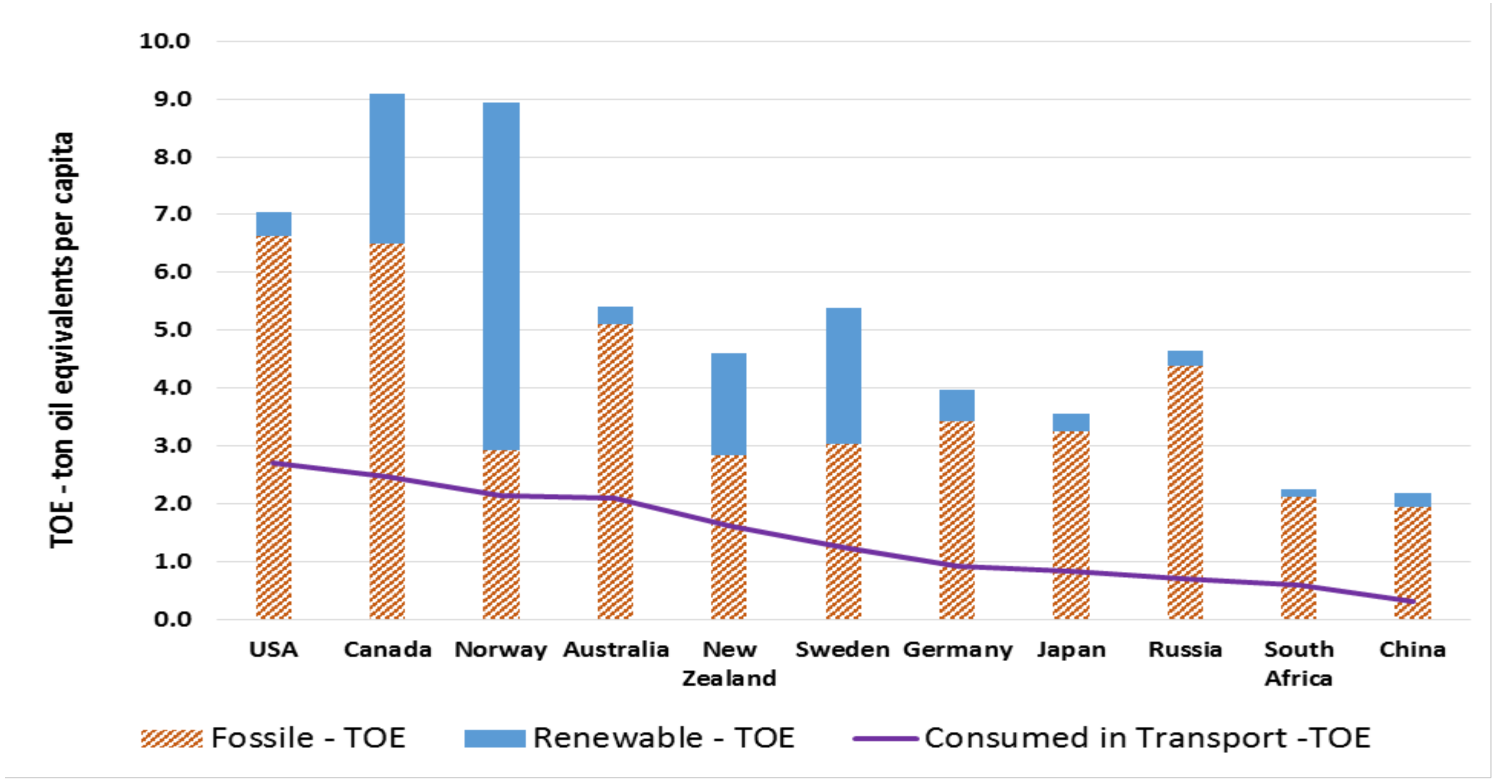
1 – Low and Zero carbon fuels : Norway is unique since 75% of fossil fuel is used in the transport sector, which makes electrification of transport a logical choice to cut CO2 by 40%

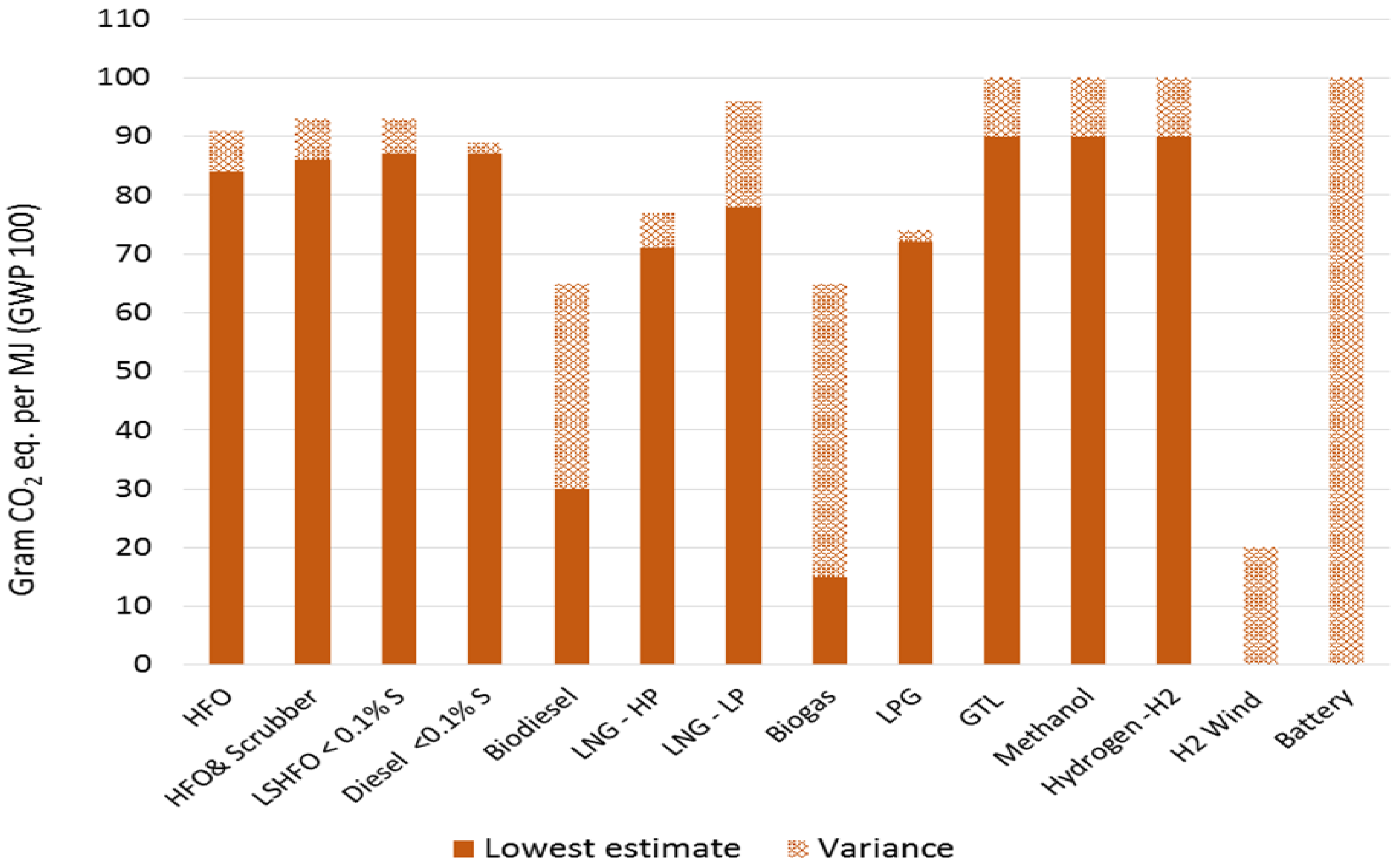
(Assumption: Norwegian grid is renewable, and not a mix due to import and export)



Source : BP (2016) Statistical Review of World Energy June-2016; IEA (2014) Energy efficiency indicators for transport

1 – Low and zero carbon fuels: Renewable-energy based electricity + 3rd generation Biofuels

Global electricity grid based on 100% renewables and 3rd generation biofuels are required if IMO 2050 target shall be reached through alternative fuels



Climate impact (100 years) of various power source (gram CO2-eq. per Mj)
Source: Lindstad (2018) A review of published studies

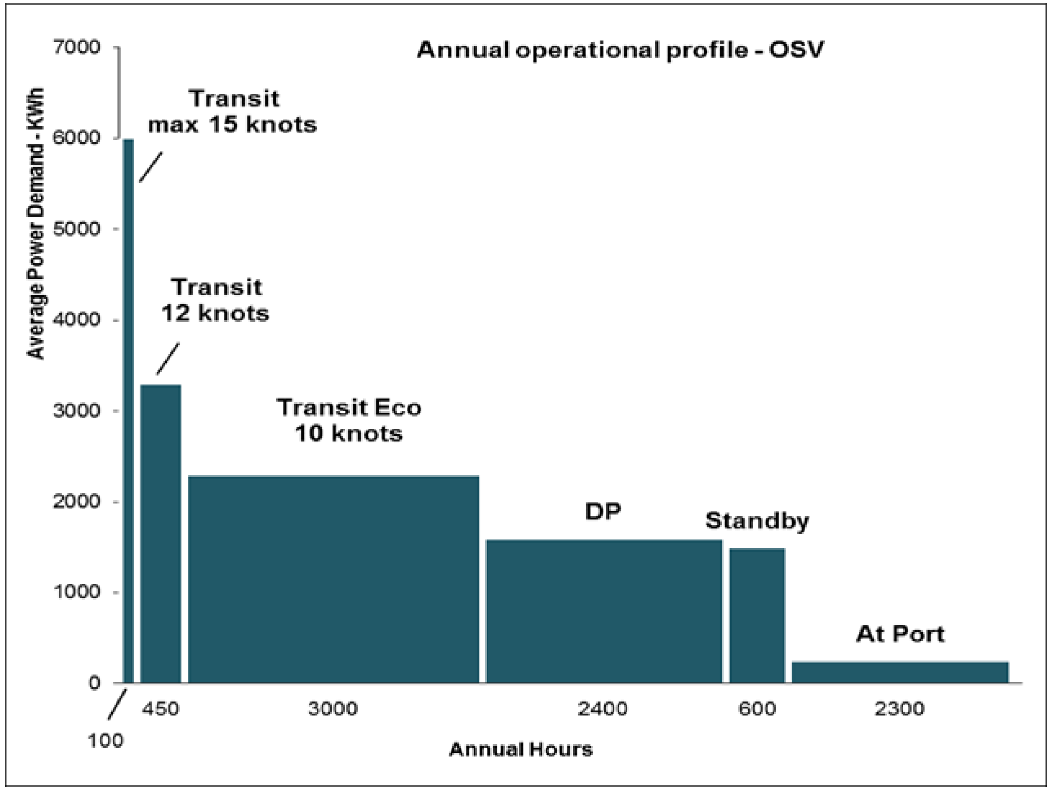
Transportation Research Part D 50 (2017) 409–417

Contents lists available at ScienceDirect

Transportation Research Part D

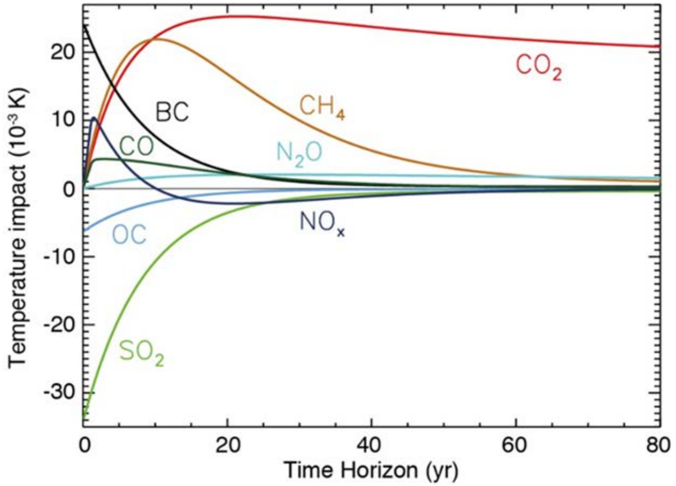
journal homepage: www.elsevier.com/locate/trd

- The Figure shows a typical annual operational profile with the associated power demands for a supply vessel operating in the North Sea (Troms Offshore, 2015; in house data; Fagerholt and Lindstad, 2000)

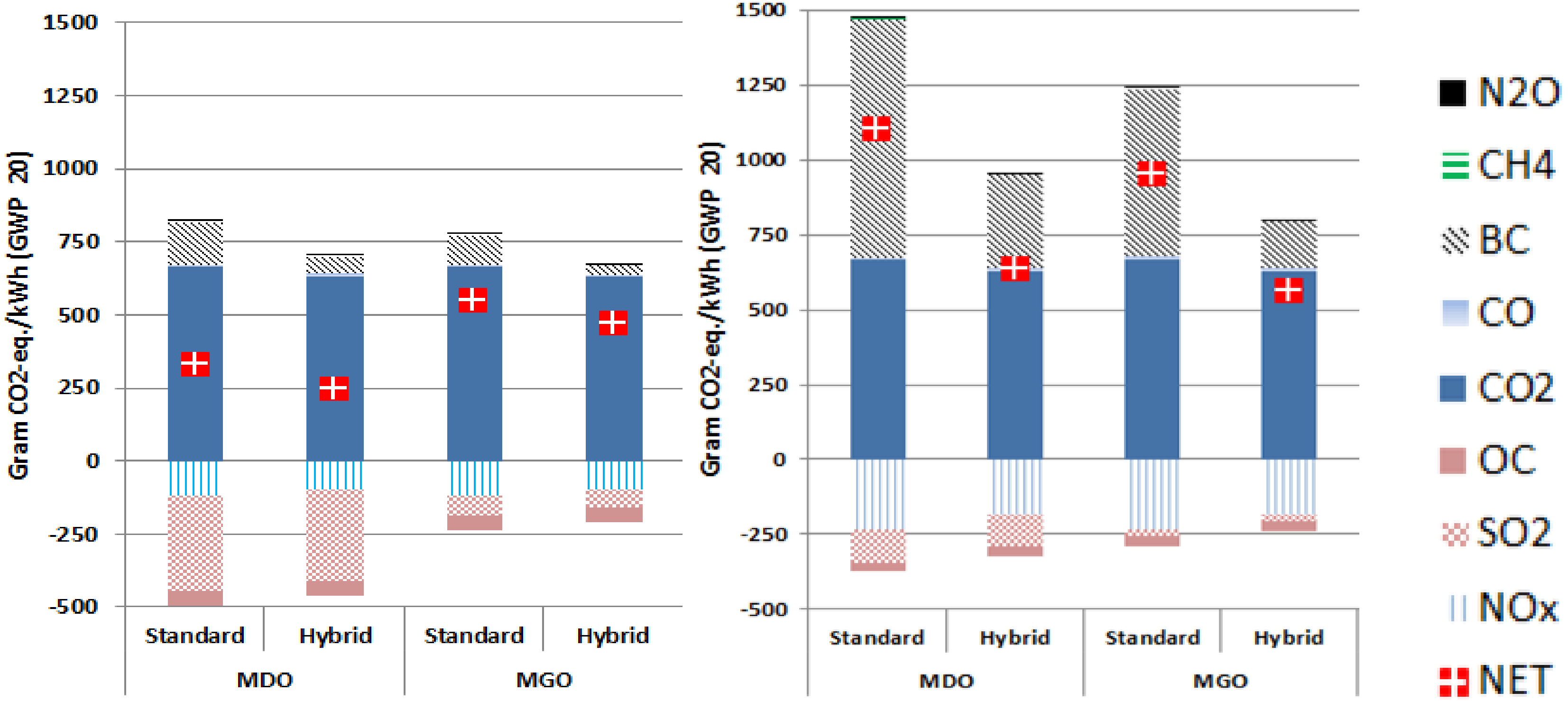


Source: Lindstad, Eskeland, Rialland, 2017. *Batteries in Offshore Support vessels - Pollution, climate impact and economics.* Transportation Research Part D 50 (2017) 409–417

The benefits of Hybrid power options are larger in the Arctic than in the North Sea

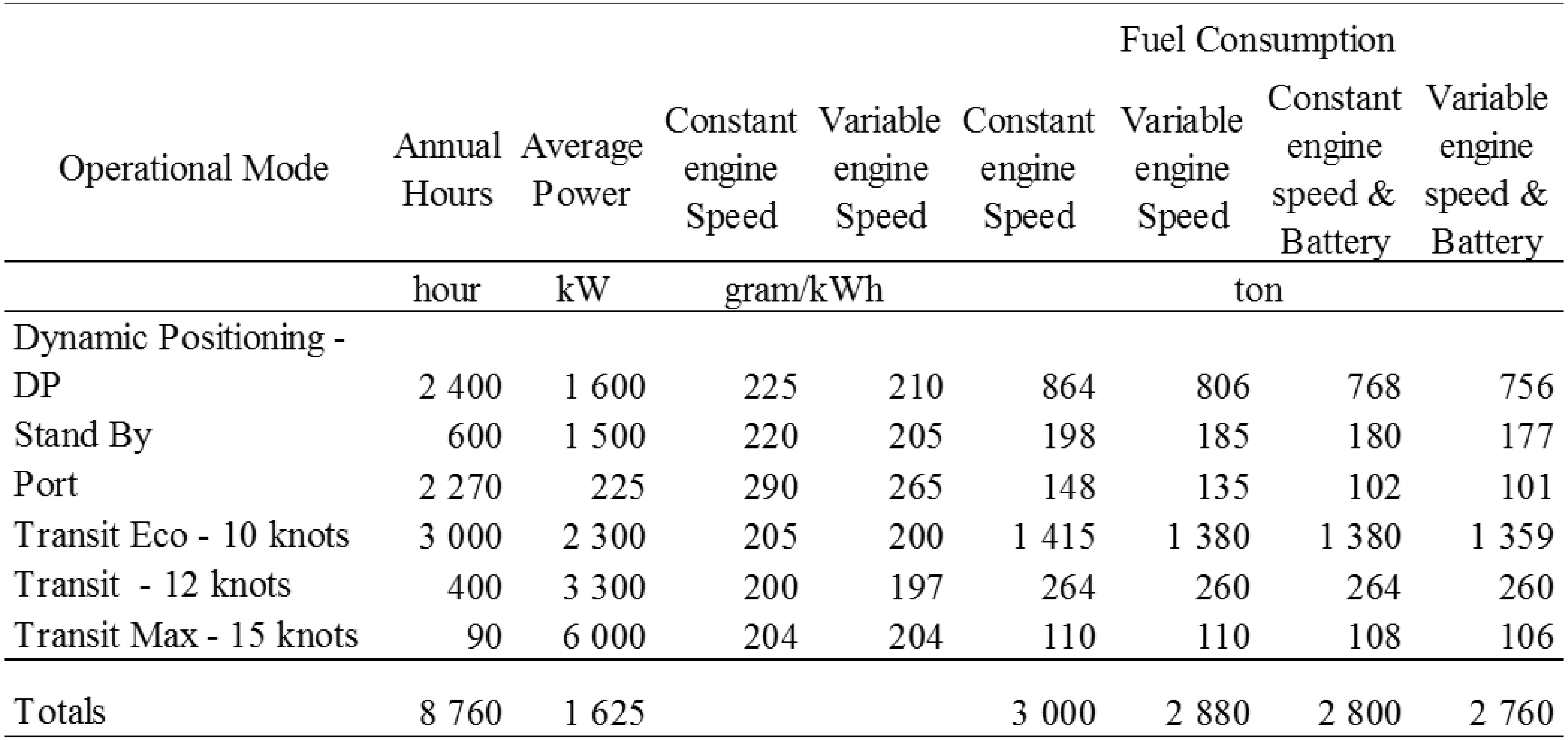


- **North Sea** **Arctic**



Source; Lindstad, H., E., Sandaas, I., 2016 *Emission and Fuel Reduction for Offshore Support Vessels through Hybrid Technology.* Journal of Ship Production and Design, Vol. 32, No. 4, Nov 2016, page 195-205.

Annual fuel consumption as a function of engine, battery and technology



Operational Mode	Annual Hours	Average Power	Constant engine Speed	Variable engine Speed	Fuel Consumption Constant engine Speed	Variable engine Speed	Constant engine speed & Battery	Variable engine speed & Battery
	hour	kW	gram/kWh		ton			
Dynamic Positioning - DP	2 400	1 600	225	210	864	806	768	756
Stand By	600	1 500	220	205	198	185	180	177
Port	2 270	225	290	265	148	135	102	101
Transit Eco - 10 knots	3 000	2 300	205	200	1 415	1 380	1 380	1 359
Transit - 12 knots	400	3 300	200	197	264	260	264	260
Transit Max - 15 knots	90	6 000	204	204	110	110	108	106
Totals	8 760	1 625			3 000	2 880	2 800	2 760

Potential power setups, fuels and hull designs capable of satisfying future EEDI requirements

Transportation Research Part D 63 (2018) 276–290

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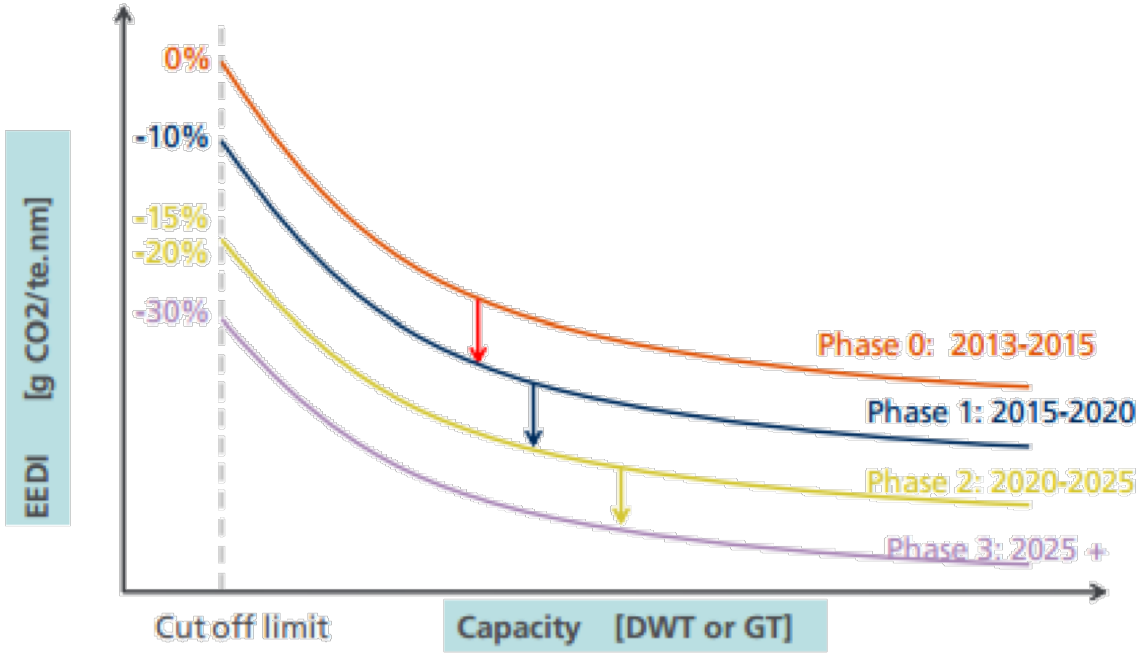
Potential power setups, fuels and hull designs capable of satisfying future EEDI requirements

Elizabeth Lindstad[a,*], Torstein Ingebrigtsen Bø[a,b]

How to meet EEDI requirements?

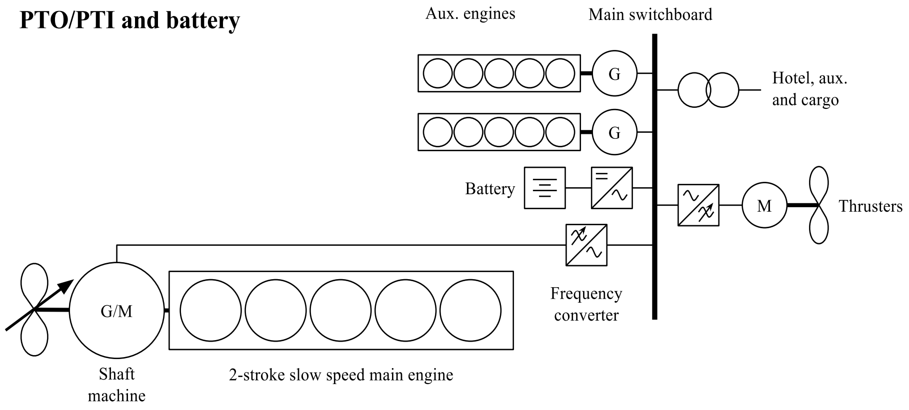
$$\mathrm{EEDI} = \frac{\mathrm{CO_2}}{\text{Tonnage} \times \text{Distance}}$$

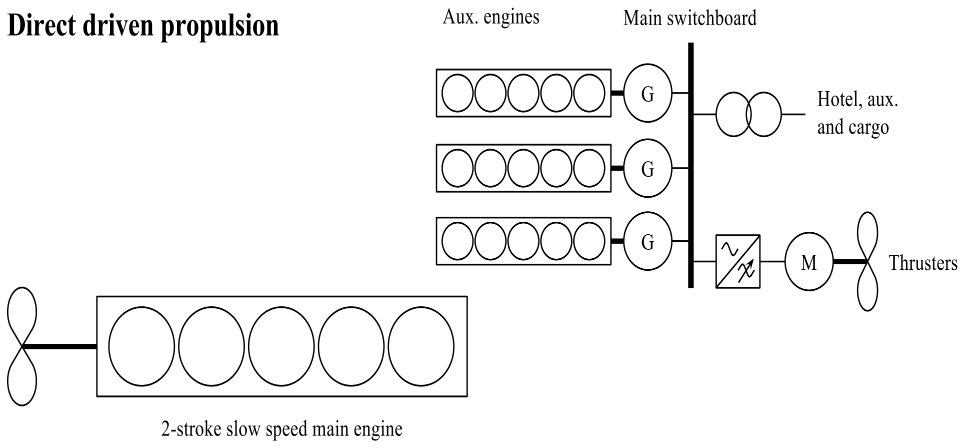


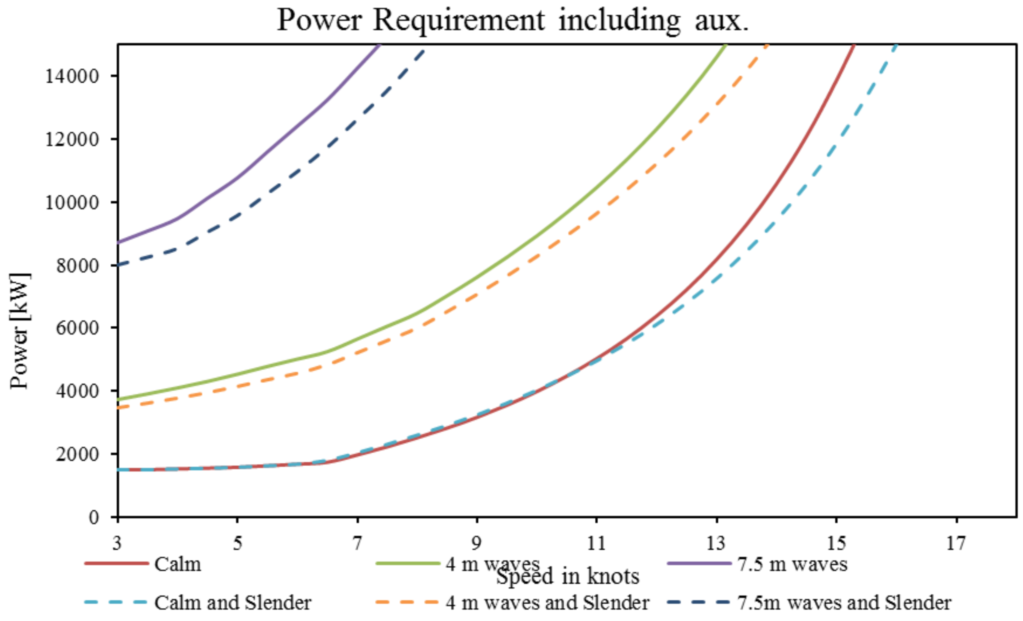
Assessed options

AS IS: Full-bodied Aframax tanker with direct driven FP propeller

To Be:
1. PTO/PTI & Battery Hybrid & CP propeller
2. Slender designs
3. LNG
4. Combinations of two or more of 1 - 3


PTO/PTI and battery

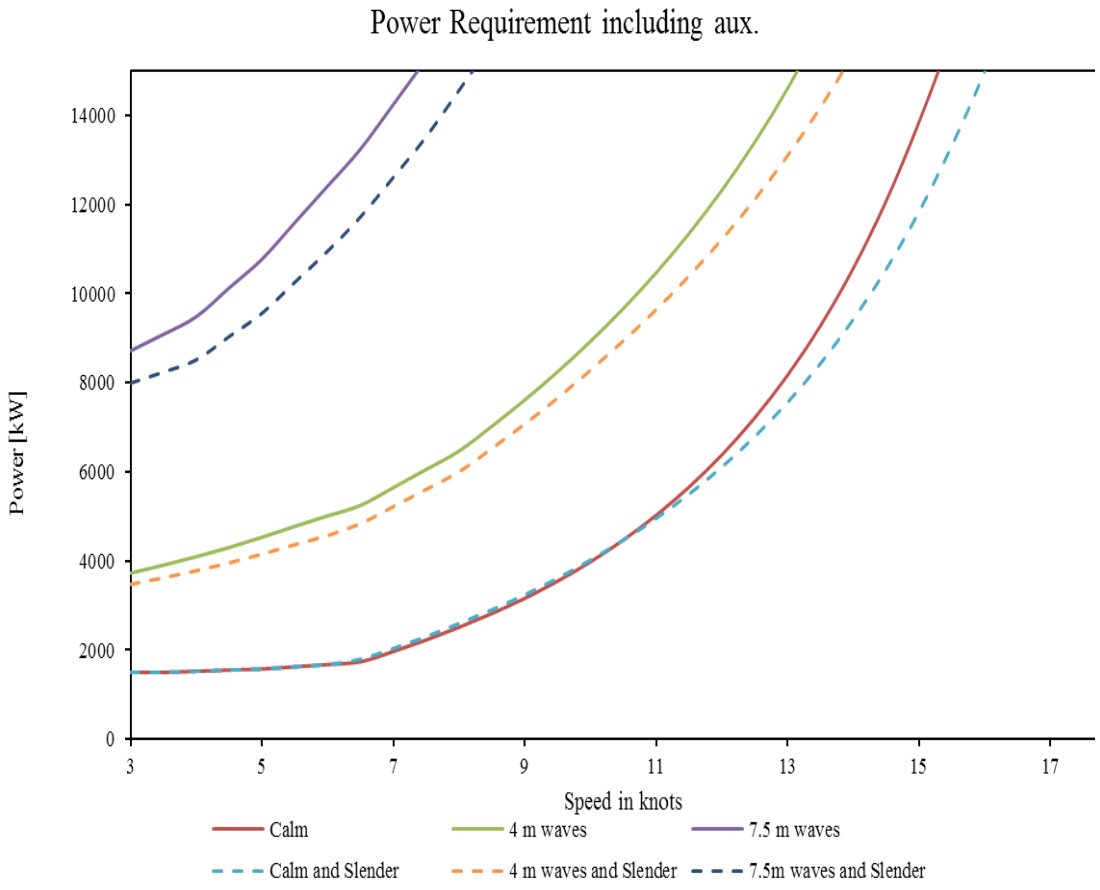

Direct driven propulsion

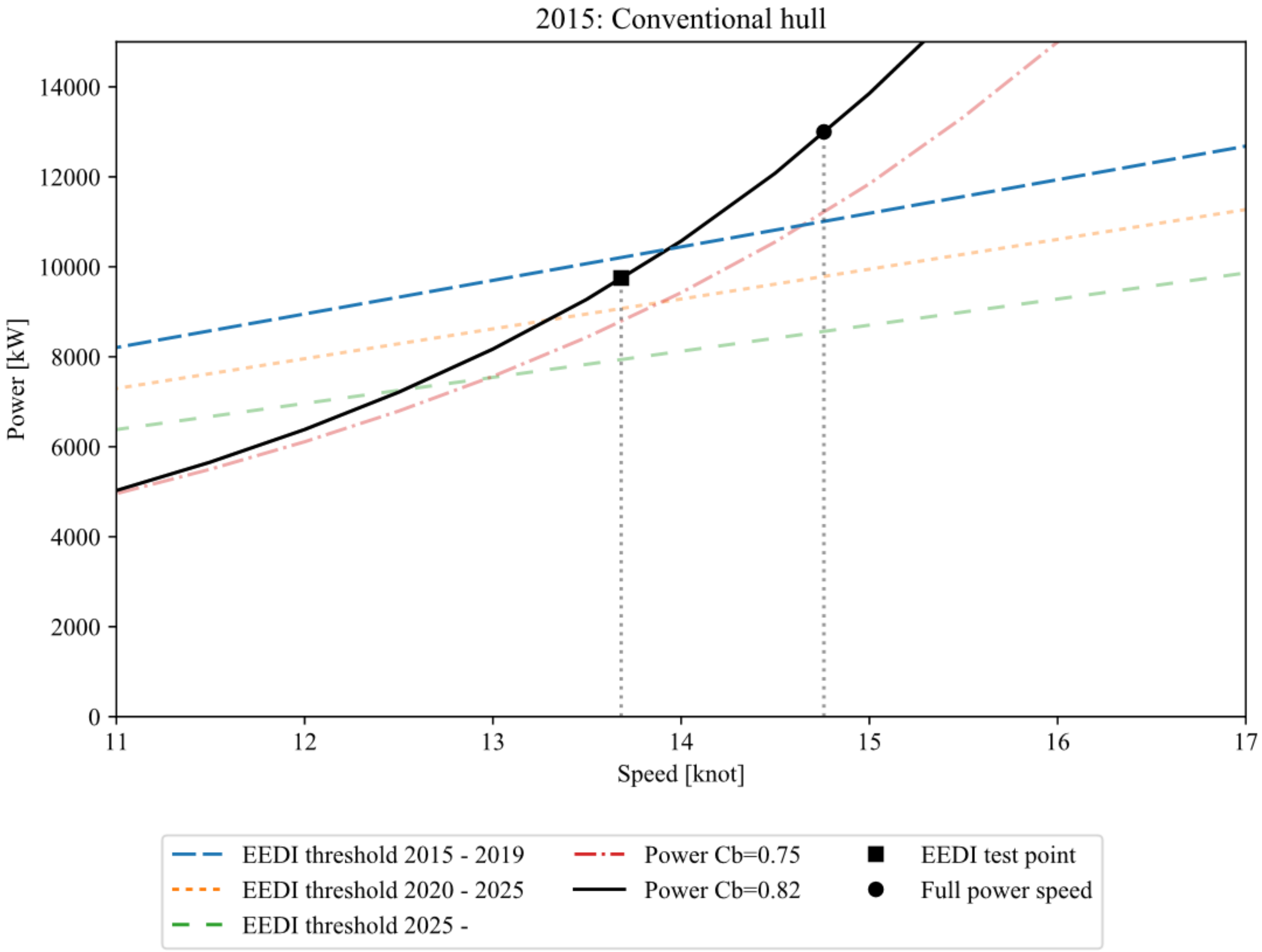


Costs of the alternative (million USD)

	Standard hull form				Slender hull form			
	13 000 kW	13 000 kW + LNG	11 000 kW + Hybrid	11 000 kW Hybrid + LNG	11 000 kW	11 000 kW + LNG	9800 kW + Hybrid	9800 kW + Hybrid + LNG
Vessel cost excluding power & propeller	42	42	42	42	44	44	44	44
Power & propeller cost	8	8	7.3	7.3	7.3	7.3	6.9	6.9
Cost hybridization			3.5	3.5			3.5	3 .5
Cost LNG		7.2		7.2		6.4		6.4
Total Cost	50	57.2	52.8	60	51.3	57.7	54.4	60.8

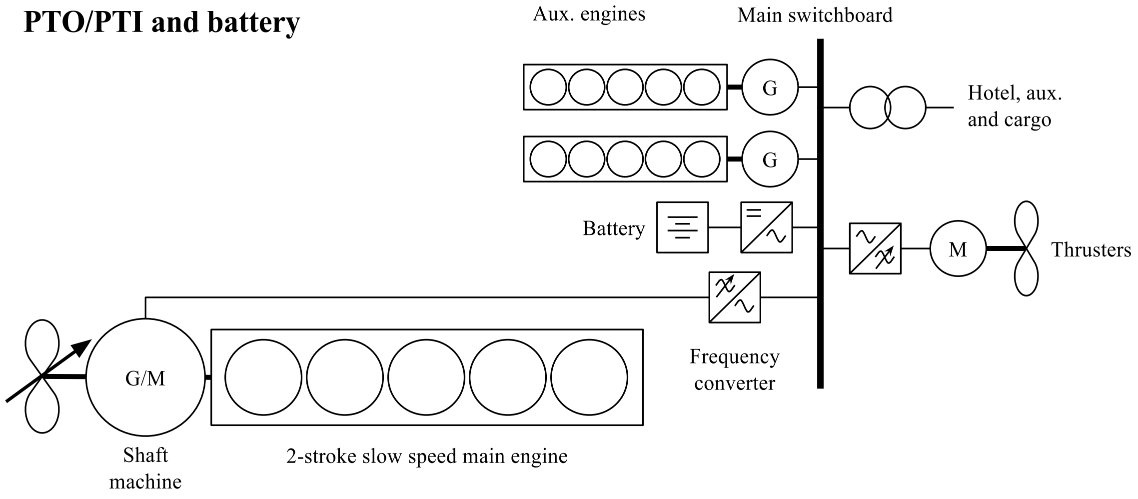
Option 1: Slender hull designs

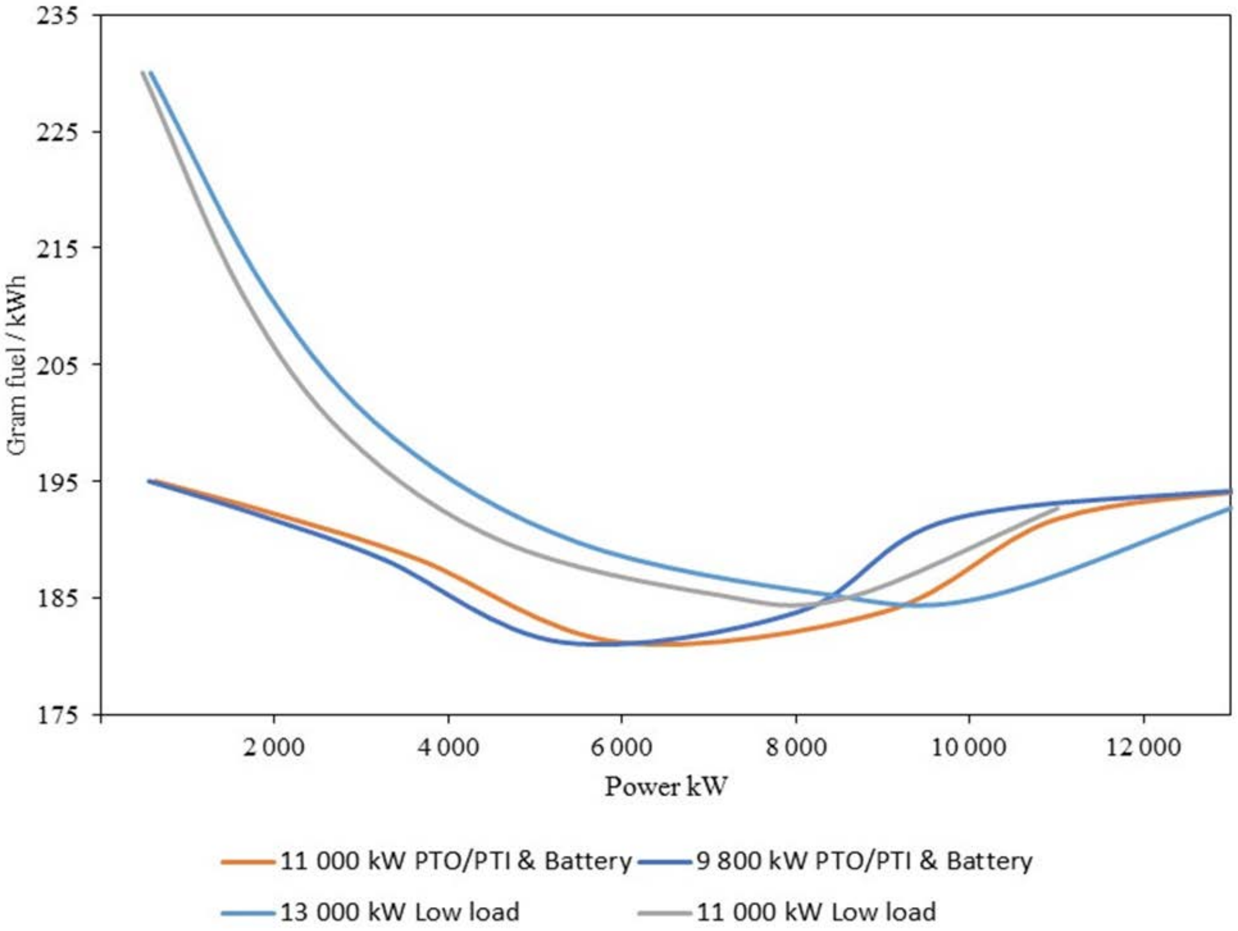




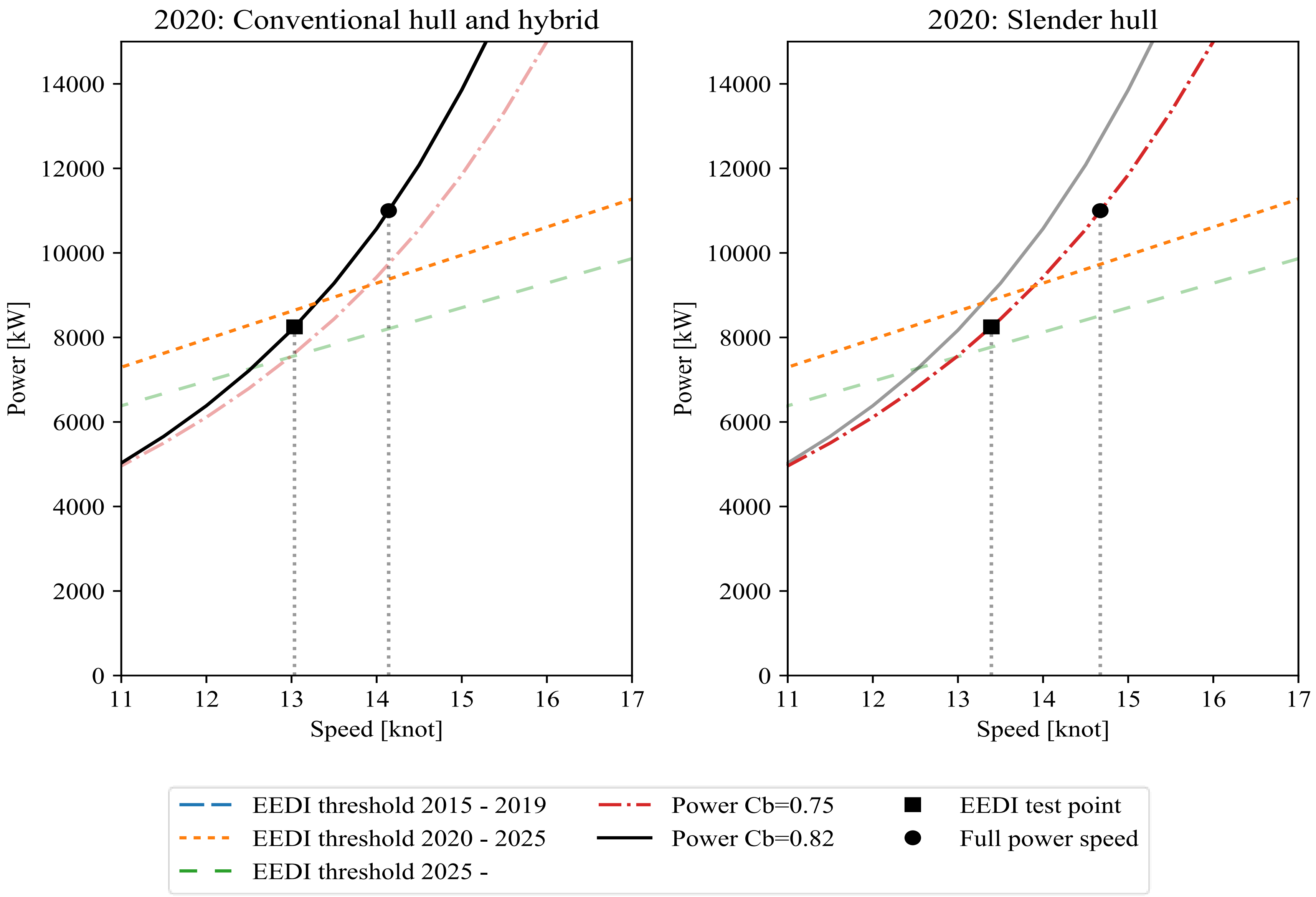
Source: Lindstad & Bø (2018)

Option 2: PTO/PTI & Battery Hybrid & CP propeller





Source: Lindstad & Bø (2018)



Source: Lindstad, E., Bø, T., I., 2018. *Potential power setups, fuels and hull designs capable of satisfying future EEDI requirements.* Accepted for publication in Transportation Research Part D

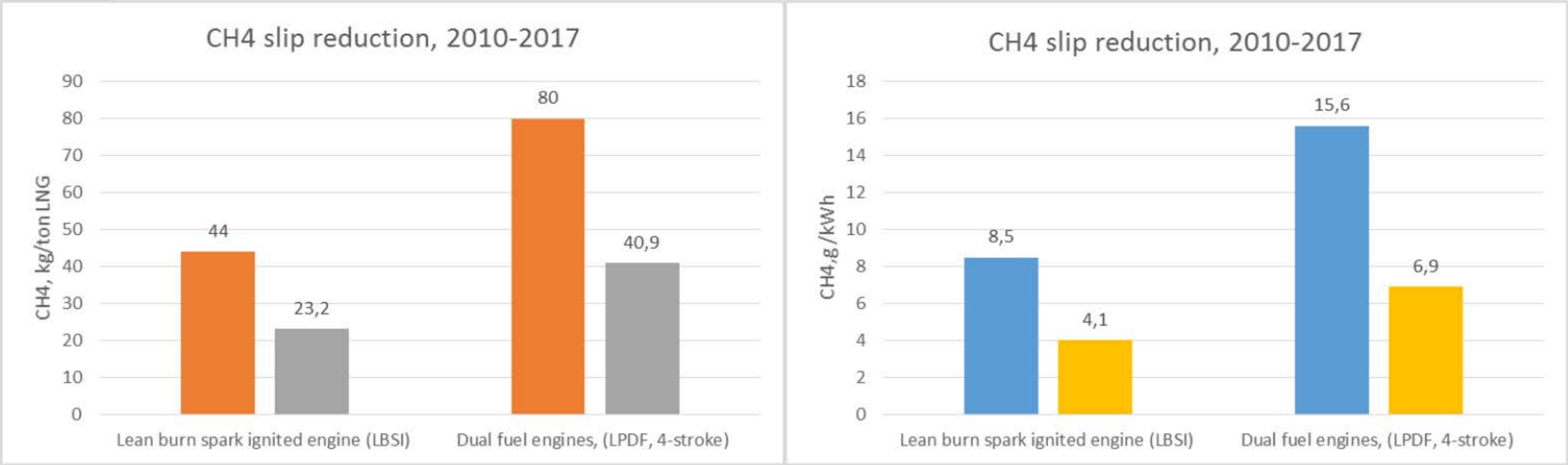
Option 3: LNG

- Up to 25 % reduction in CO_2 through lower carbon factor and higher heating value

5 - 20 % reduction in GHG emissions when including methane slip

Reduction factors compared to MGO	LBSI	LPDF*, 4-stroke Medium speed	LPDF, 2-stroke Slow speed	HPDF, 4-stroke, medium speed	HPDF, 2-stroke, slow speed
CO_2	25-28%	20-25%	20-26%	20-24%	20-24%
NOx	85-90%	75-90%	75-90%	25-30%	25-30%
SOx	>99%	98-99%	95-99%	95-97% **	95-97% **
Particulates	>99%	95-98%	95-98%	30-40%	N/A

Emissions profile of marine gas fuelled engines (Source: Stenersen & Thonstad, 2017)



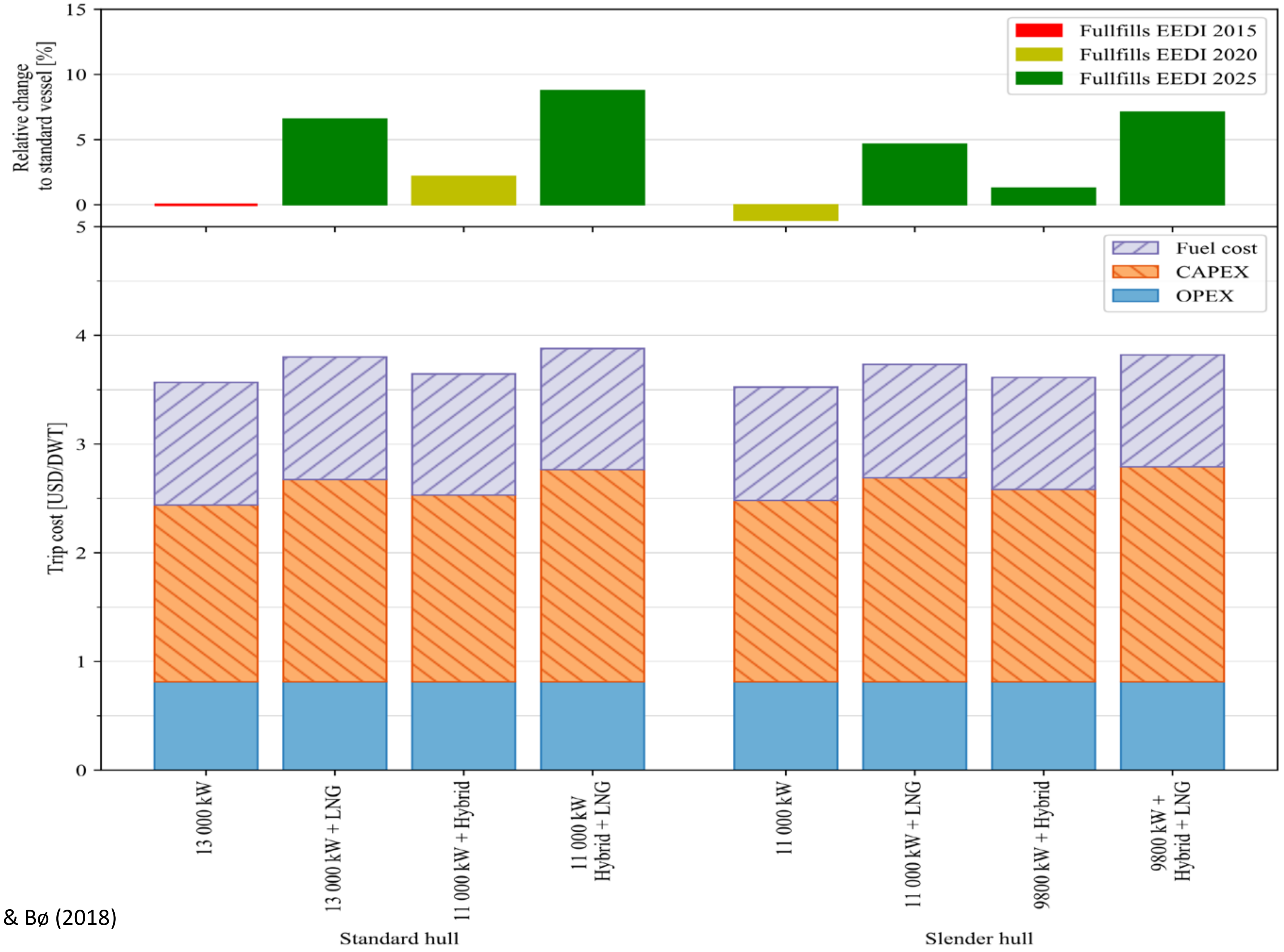
CH4 emission factors (Source: Stenersen, 2018)

Source: Lindstad & Bø (2018)

*) Highest reduction factors for DF obtained with micro ignition **) Dependant of S-content in pilot fuel

Senter for

Roundtrip voyage cost for vessels sailing at medium speed



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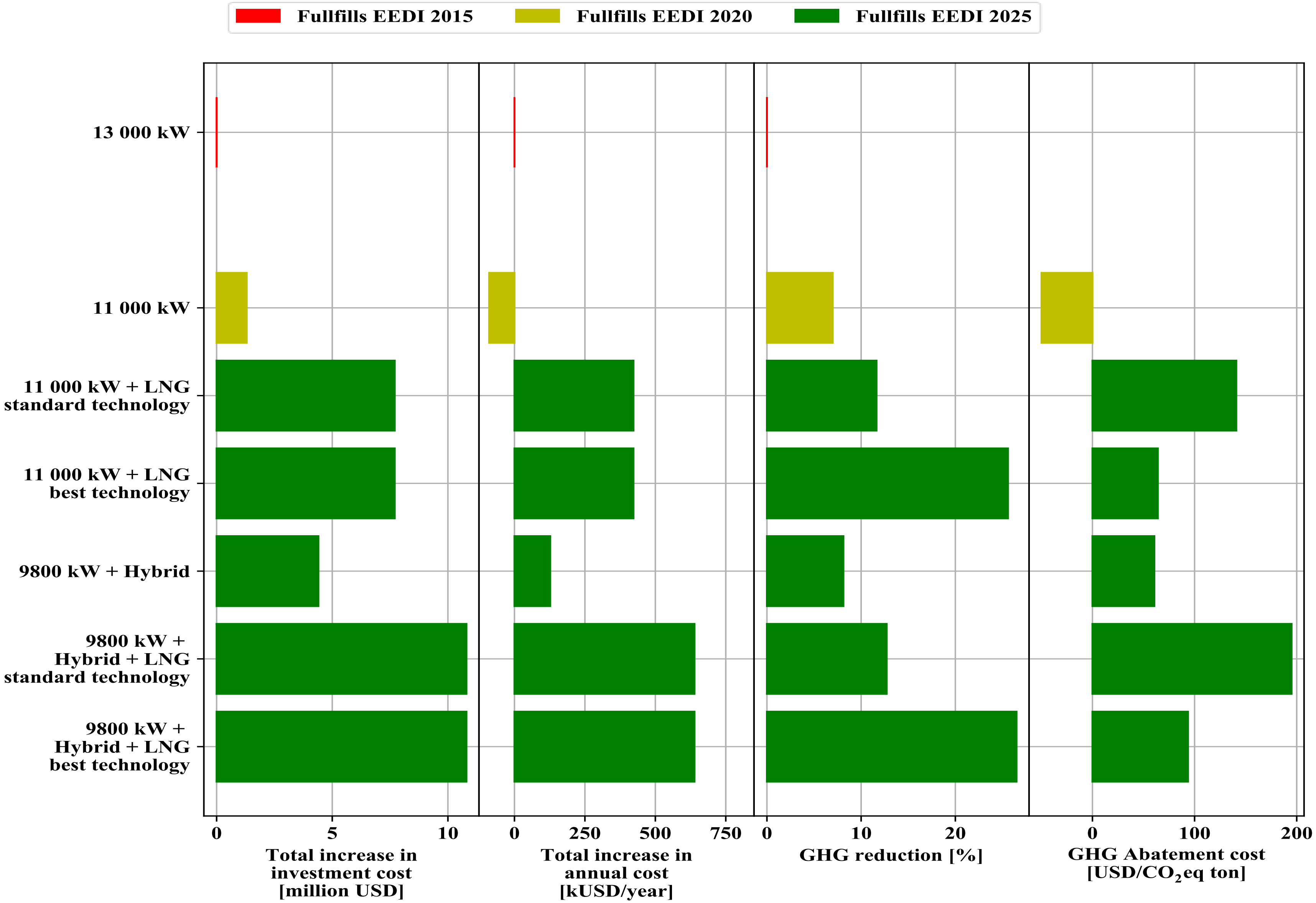
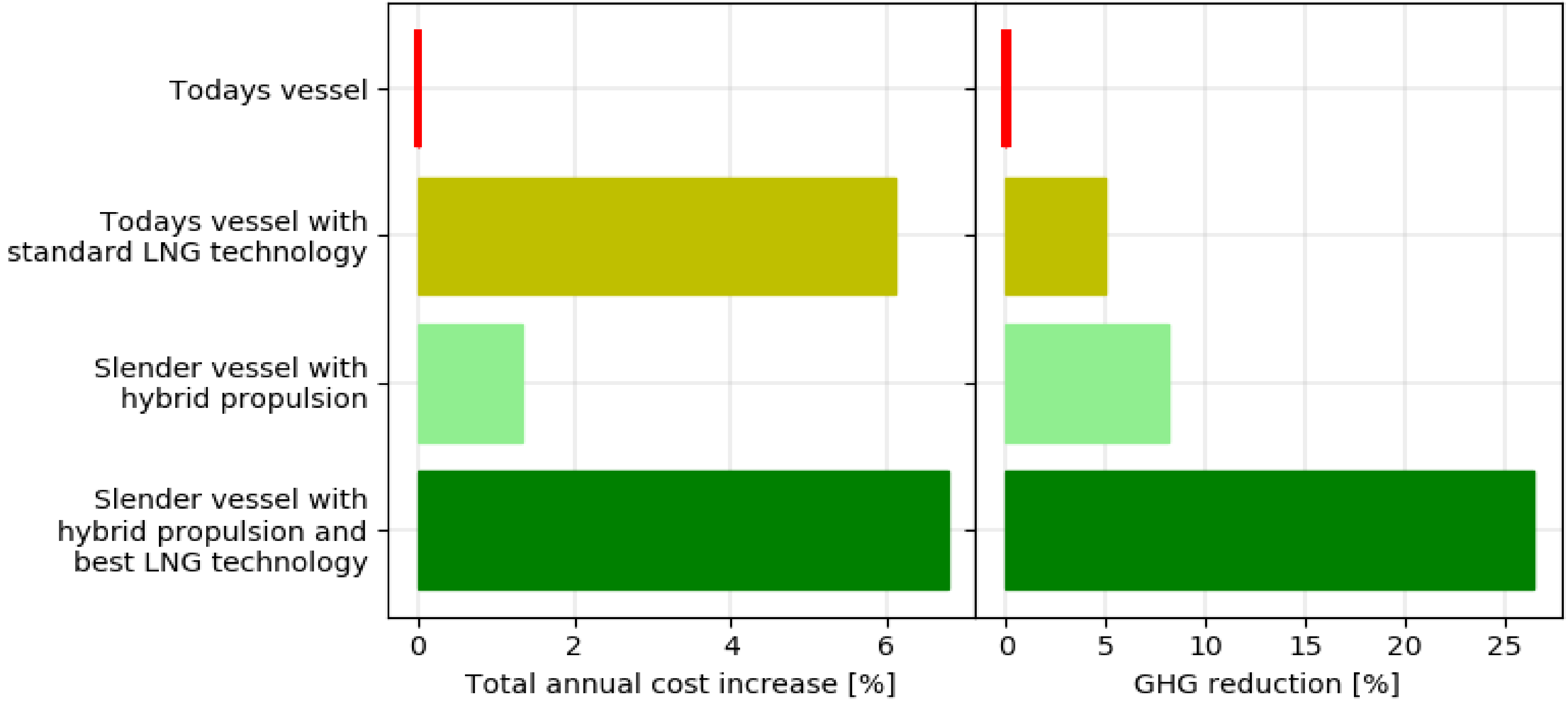
Source: Lindstad & Bø (2018)

Investment & Yearly cost - GHG reduction - Abatement cost



Aalto University
School of Engineering

Cost of GHG reduction options satisfying the 2025 EEDI requirements



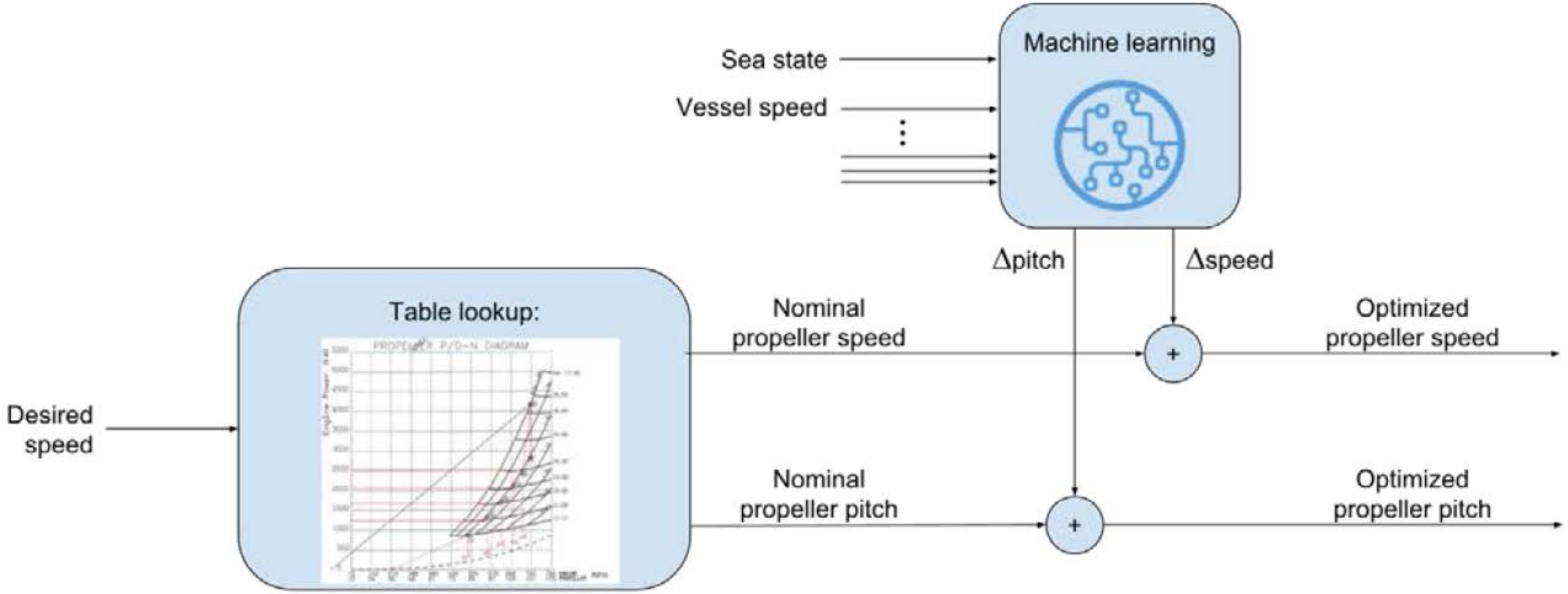
Source: Lindstad, E., Bø, T., I., 2018. *Potential power setups, fuels and hull designs capable of satisfying future EEDI requirements,* Transportation Research Part D

Source: Lindstad & Bø (2018)

Automatic tuning - through machine learning - of combinator curves for Propulsion - ATTMAL

The primary objective of the ATTMAL project, is to develop an automatic controller of propeller speed and pitch to reduce emission and fuel consumption of larger seagoing vessels, both on newbuildings and for retrofit on existing vessels with CP-propeller.

MAROFF – ATTMAL Research Project – Project description



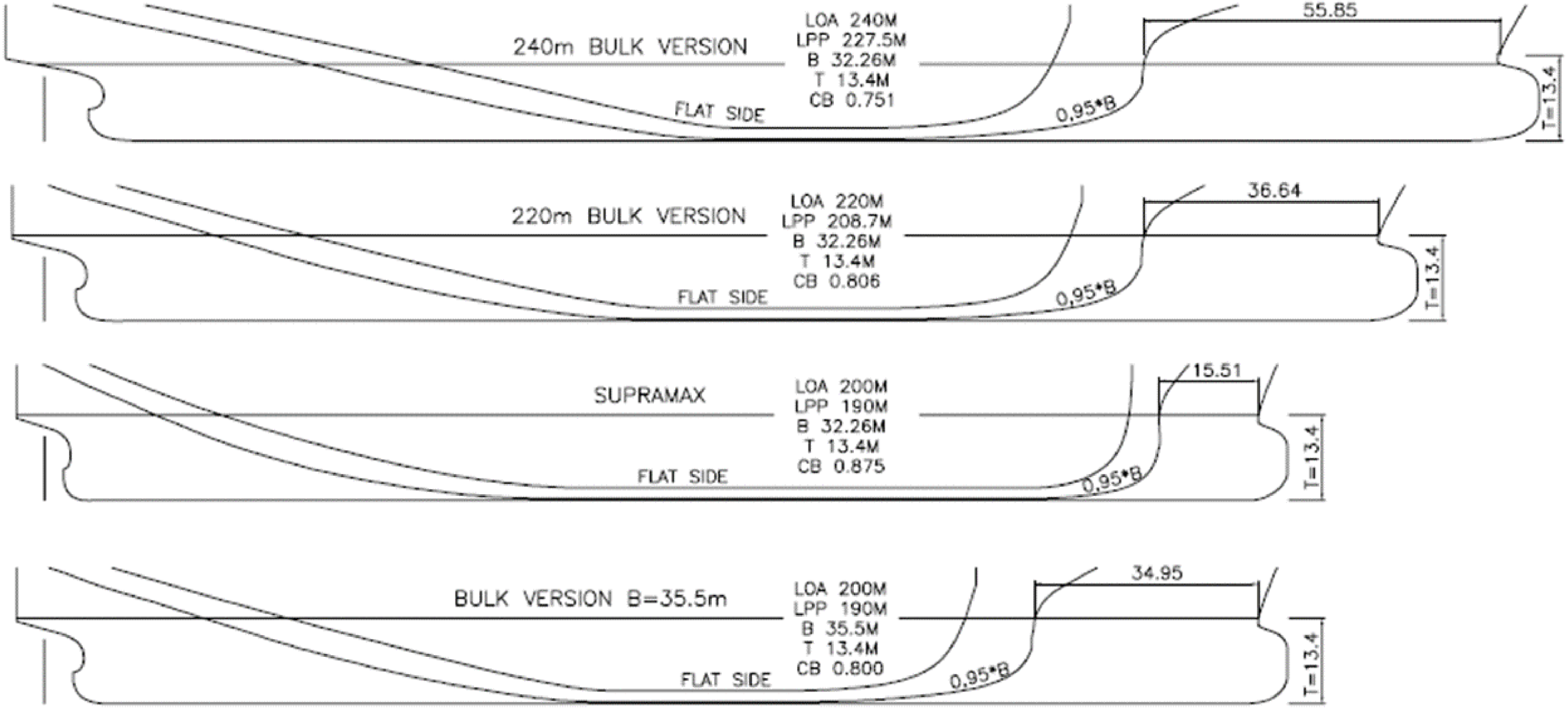
IPN –Application Optimal control of cpp propeller by use of machine learning Main objectives

- Demonstrate a full-scale pilot system for optimal control of CPP propeller
- Develop algorithms for automatic adjustment of propeller speed and pitch during operations
- Evaluate environment impact on existing fleet or typical ship types
- Evaluate business cases for
  - Retrofit
  - New buildings?

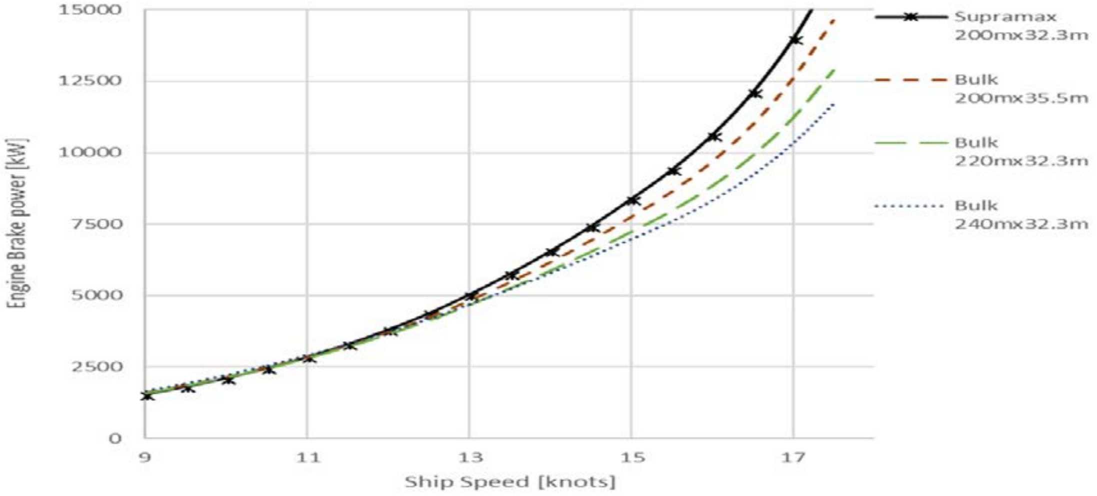
Work packages

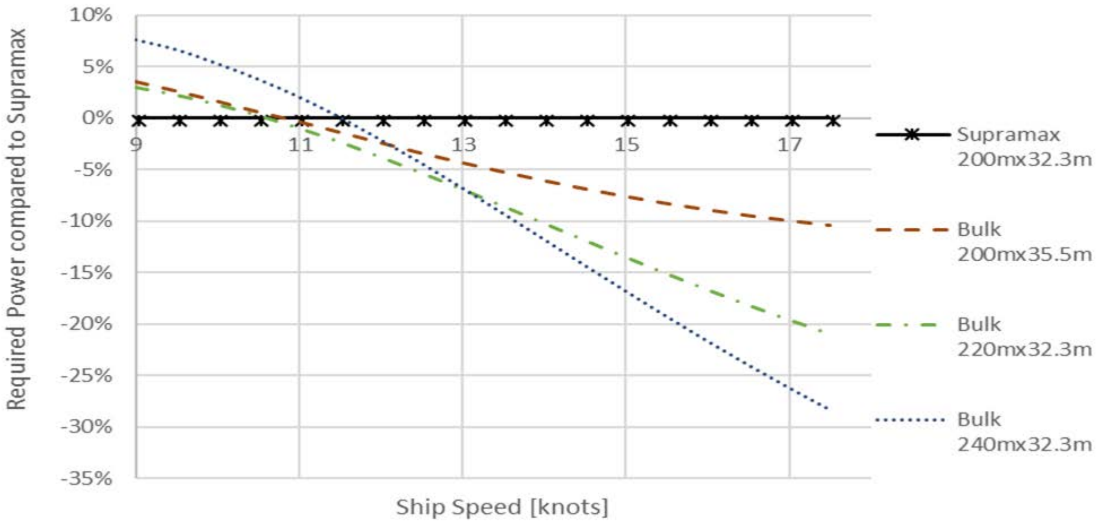
- WP 1 – Simulator (SO – Torstein B)
- WP 2 – AI and control (SÅ – NN)
- WP 3 – Pilot (SÅ - NN)
- WP 4 – Environmental impact and business models (SO – Elizabeth)
- WP 5 – Dissemination and Exploitation
- WP 6 – Project managament

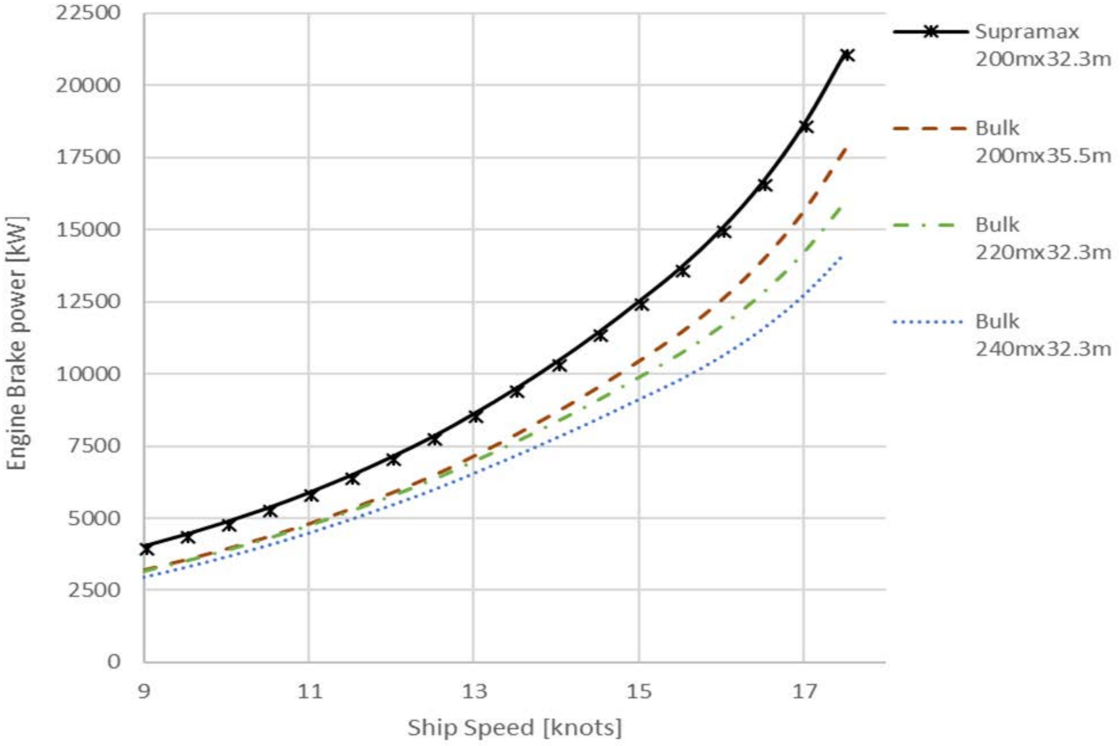
Bridging the Gap : Design speed, Boundary speed, Economic speed and Environmental speed calm & Hs=3m

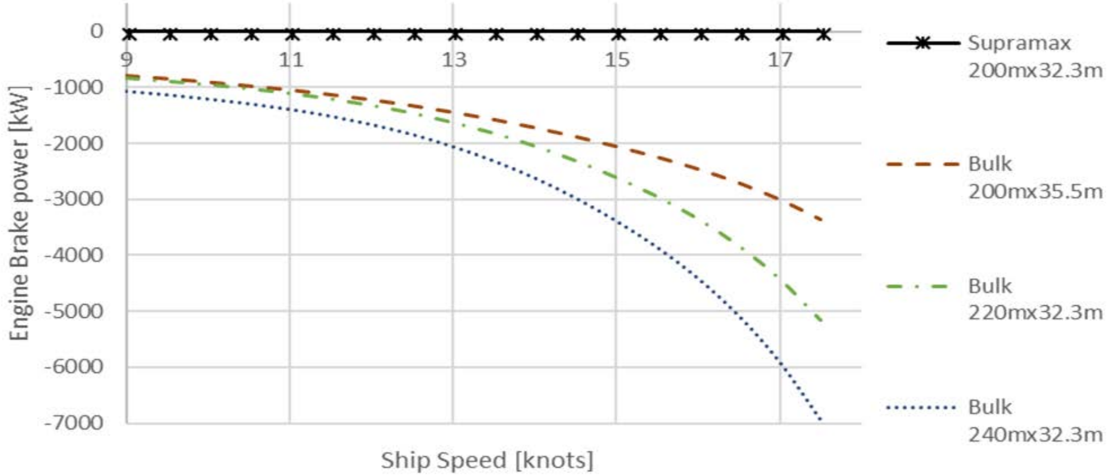


Bridging the Gap : Design speed, Boundary speed, Economic speed and Environmental speed calm & Hs=3m

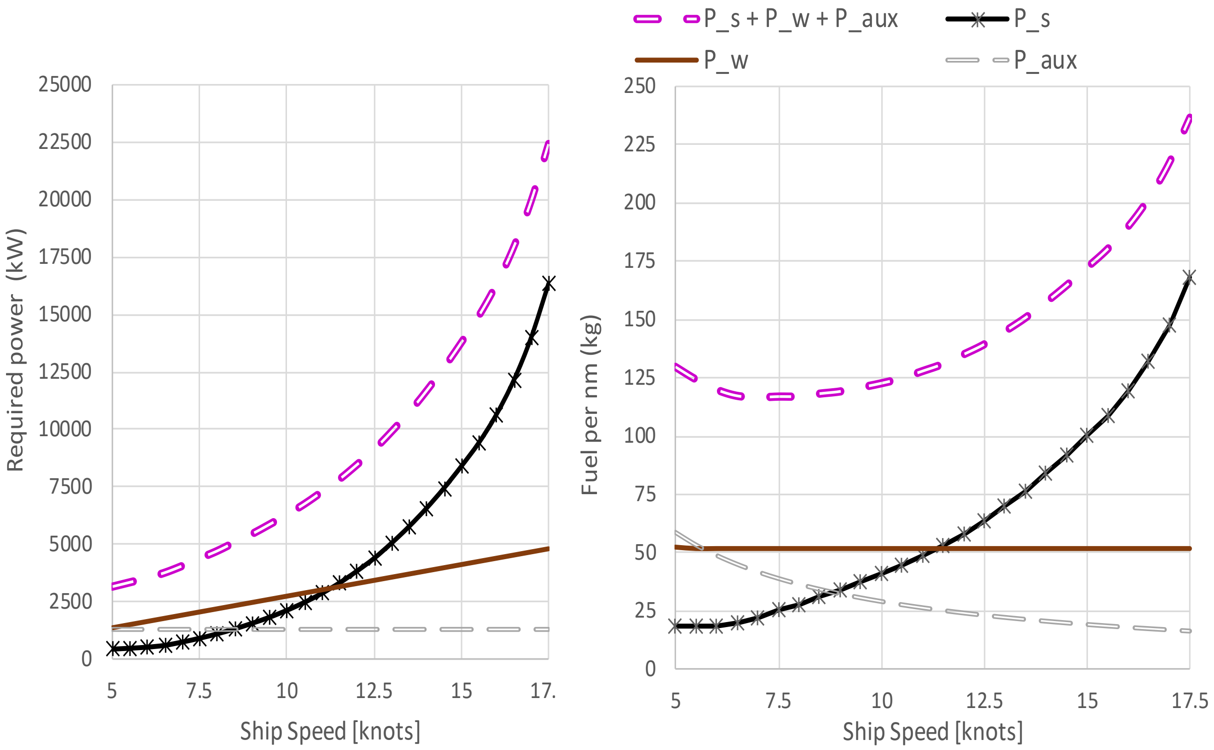


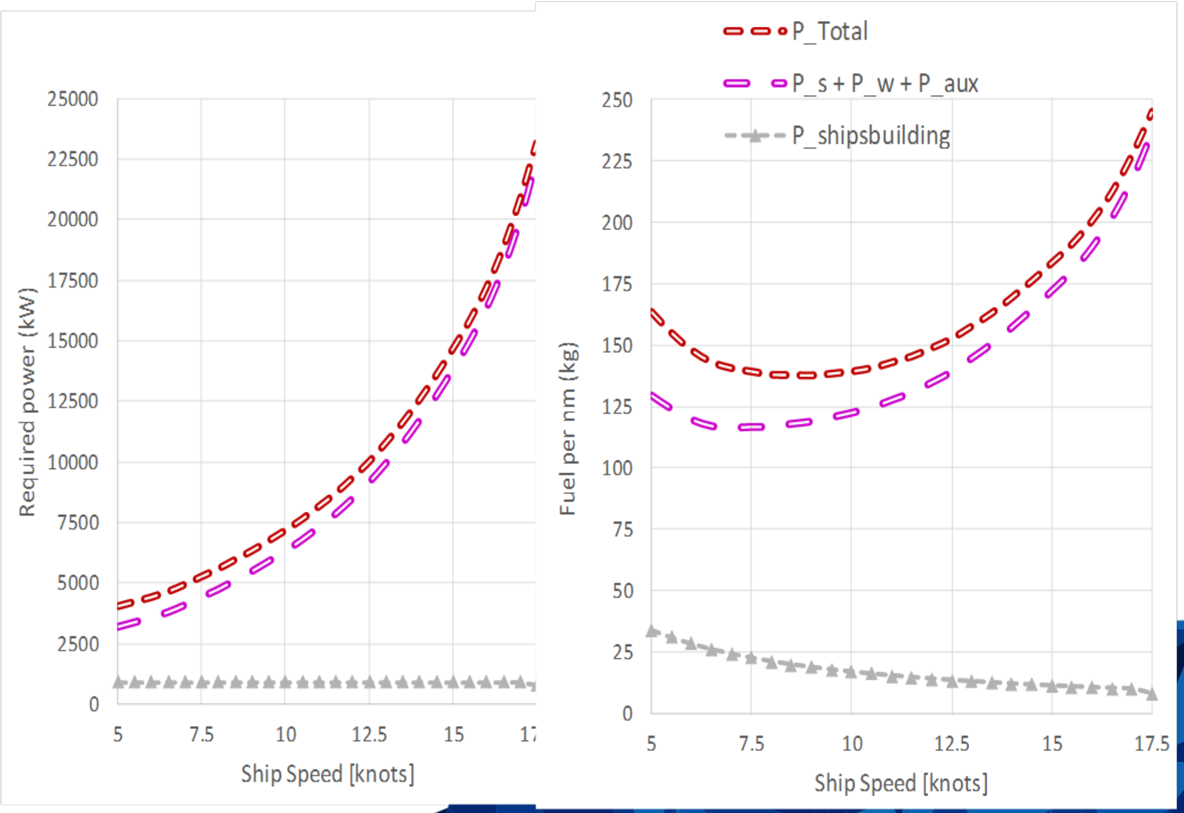




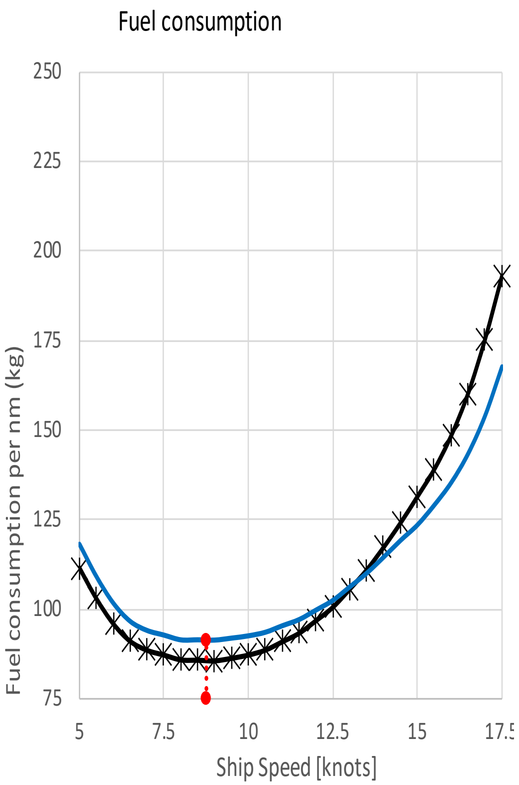


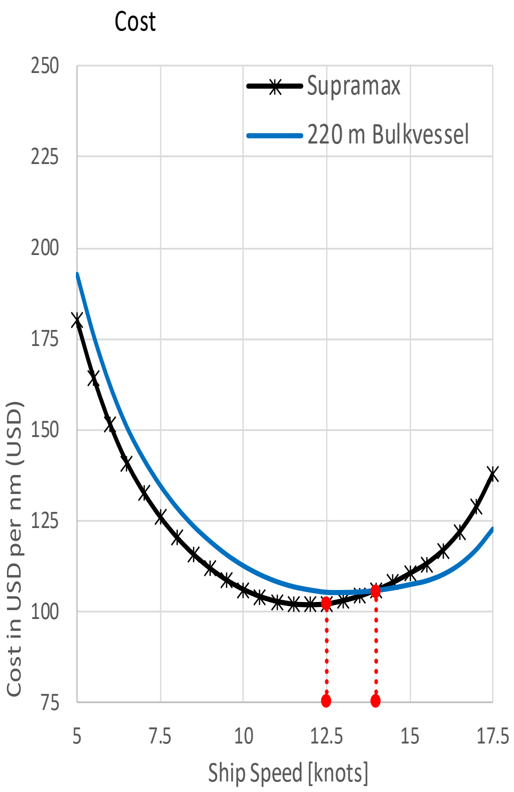
Power and Fuel per nm Supramax – Environmental speed

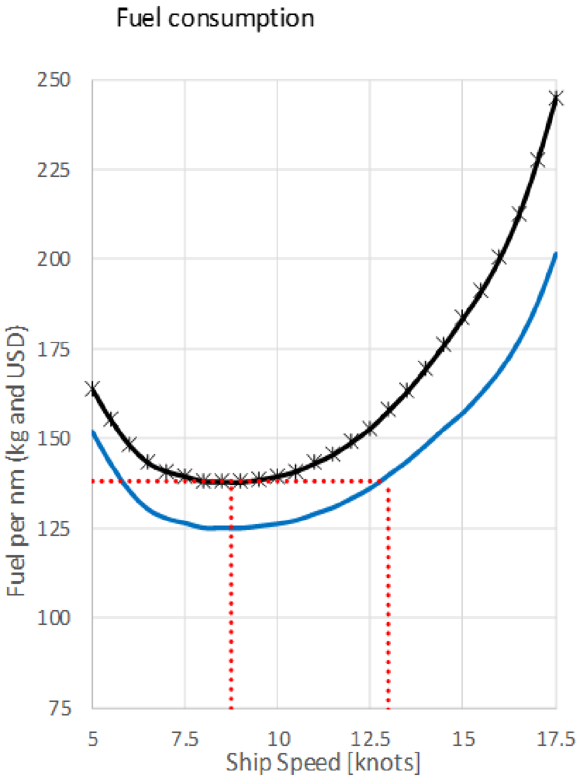


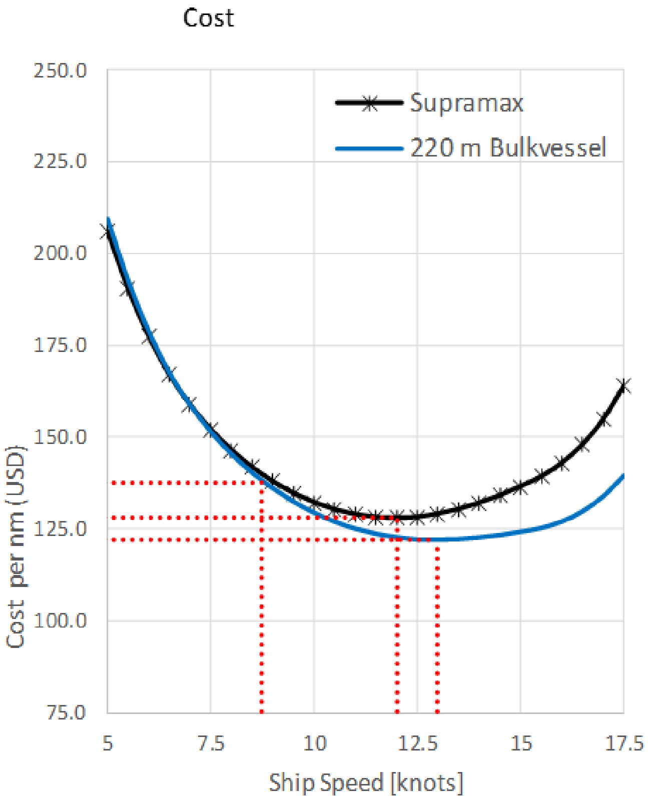


Fuel and cost calm water & Hs = 3m

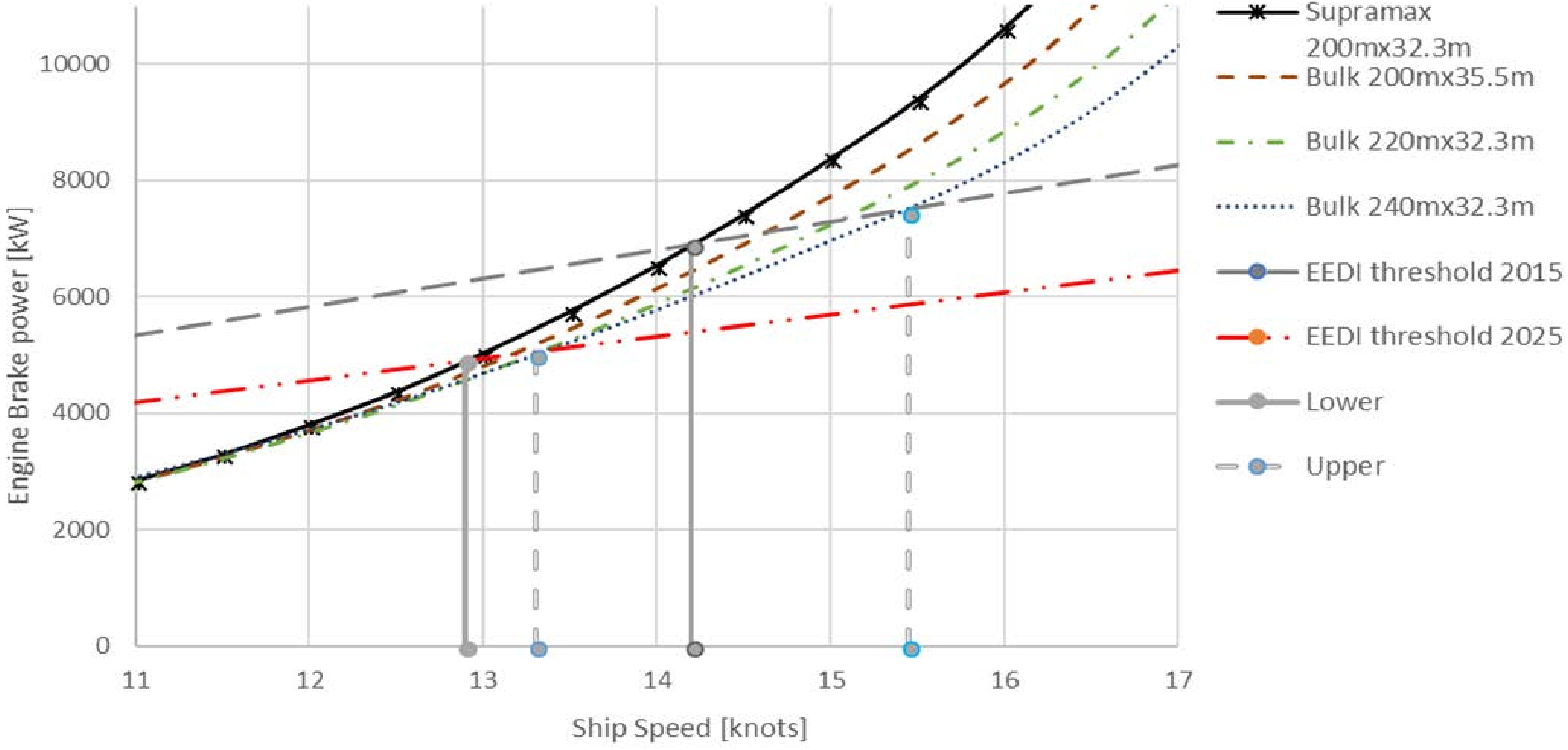

Fuel consumption


Cost


Fuel consumption


Cost

Stricter EEDI thresholds gives less reward for energy efficient – 2015 versus 2025 requirements



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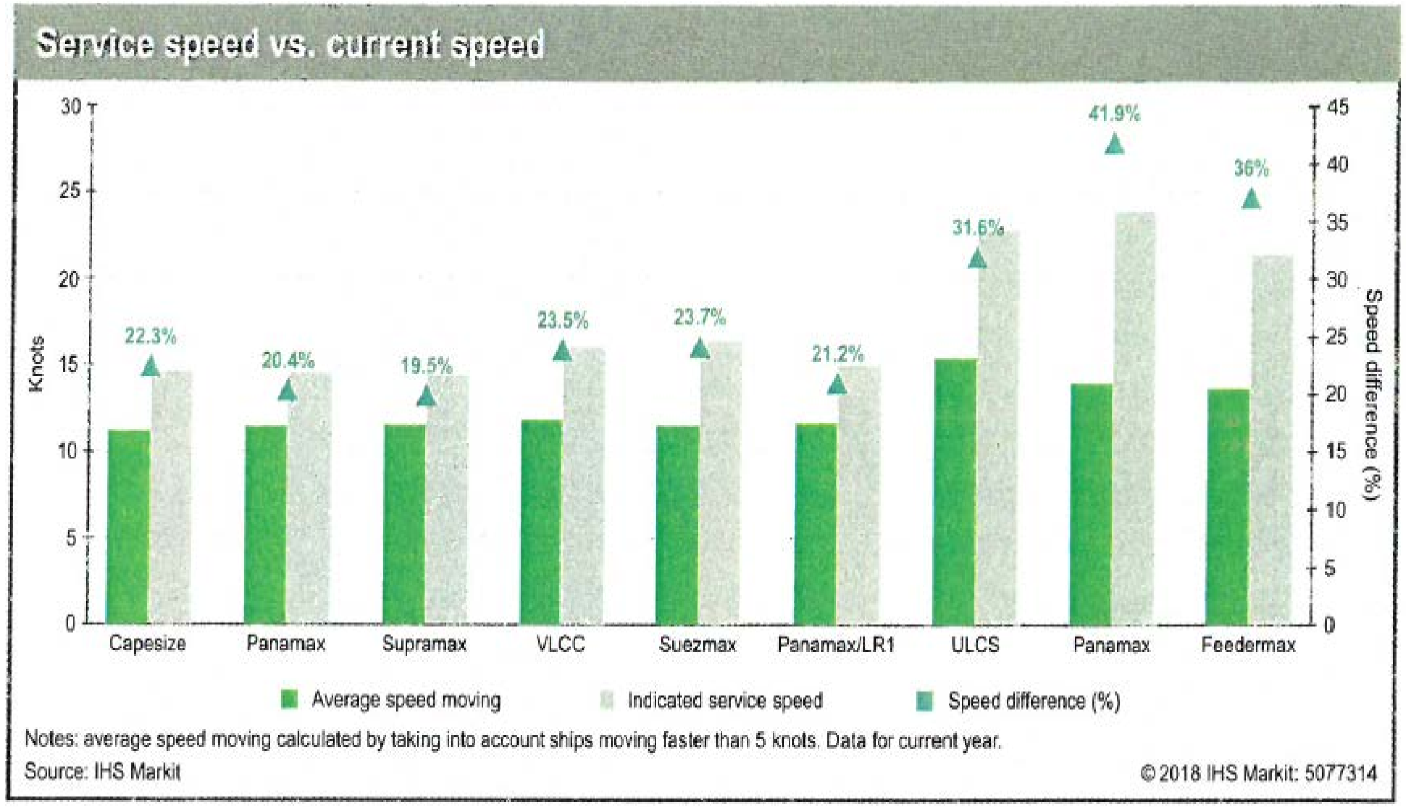
Pace race

Slow steaming not a sulphur cap saviour



Service speed vs. current speed

Notes: average speed moving calculated by taking into account ships moving faster than 5 knots. Data for current year.

Source: IHS Markit

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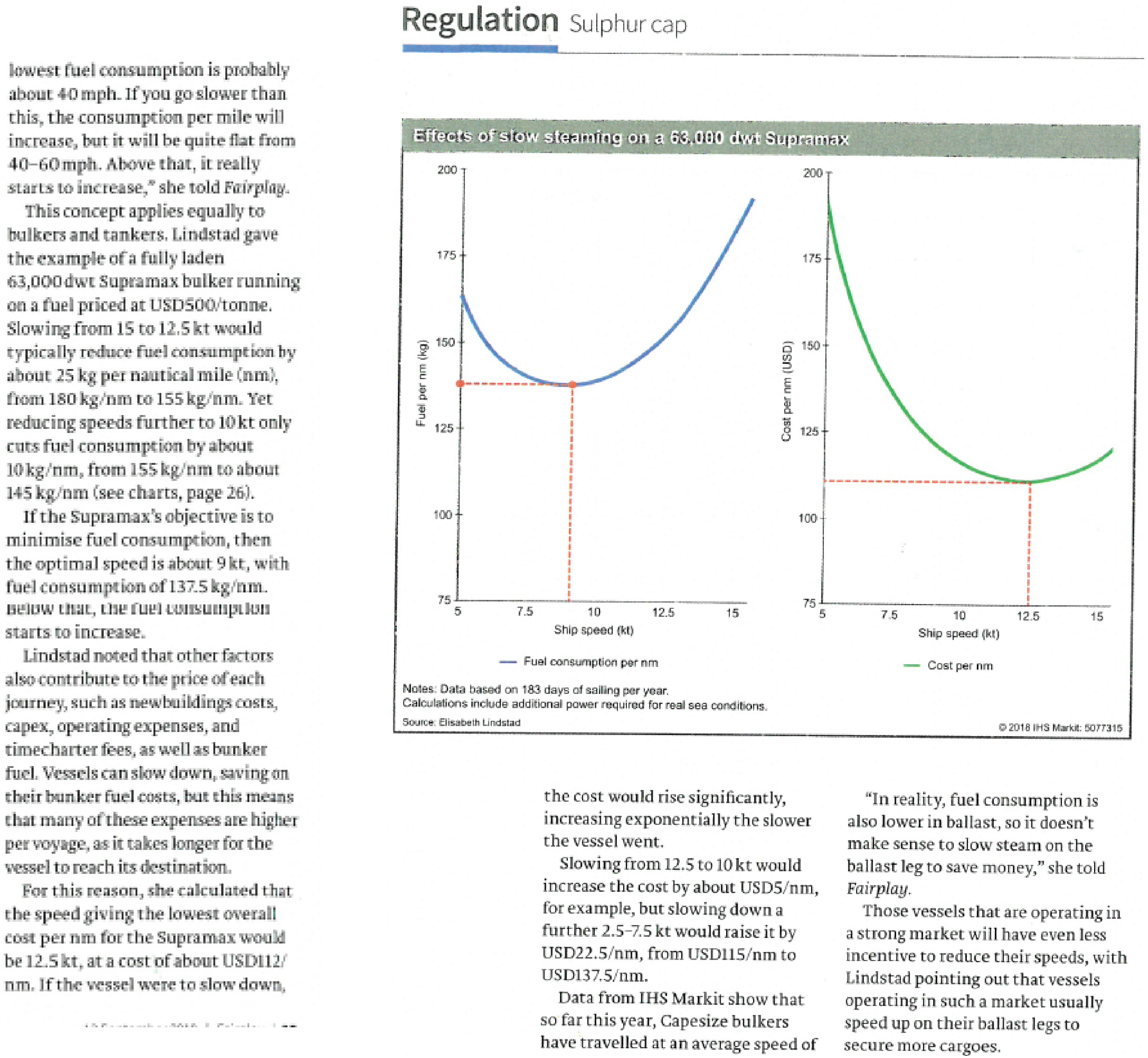
Supramax fuel and cost Elizabeth Lindstad



Regulation Sulphur cap

lowest fuel consumption is probably about 40 mph. If you go slower than this, the consumption per mile will increase, but it will be quite flat from 40–60 mph. Above that, it really starts to increase," she told *Fairplay*.

This concept applies equally to bulkers and tankers. Lindstad gave the example of a fully laden 63,000 dwt Supramax bulker running on a fuel priced at USD500/tonne. Slowing from 15 to 12.5 kt would typically reduce fuel consumption by about 25 kg per nautical mile (nm), from 180 kg/nm to 155 kg/nm. Yet reducing speeds further to 10 kt only cuts fuel consumption by about 10 kg/nm, from 155 kg/nm to about 145 kg/nm (see charts, page 26).

If the Supramax's objective is to minimise fuel consumption, then the optimal speed is about 9 kt, with fuel consumption of 137.5 kg/nm. Below that, the fuel consumption starts to increase.

Lindstad noted that other factors also contribute to the price of each journey, such as newbuildings costs, capex, operating expenses, and timecharter fees, as well as bunker fuel. Vessels can slow down, saving on their bunker fuel costs, but this means that many of these expenses are higher per voyage, as it takes longer for the vessel to reach its destination.

For this reason, she calculated that the speed giving the lowest overall cost per nm for the Supramax would be 12.5 kt, at a cost of about USD112/nm. If the vessel were to slow down, the cost would rise significantly, increasing exponentially the slower the vessel went.

Slowing from 12.5 to 10 kt would increase the cost by about USD5/nm, for example, but slowing down a further 2.5–7.5 kt would raise it by USD22.5/nm, from USD115/nm to USD137.5/nm.

Data from IHS Markit show that so far this year, Capesize bulkers have travelled at an average speed of

"In reality, fuel consumption is also lower in ballast, so it doesn't make sense to slow steam on the ballast leg to save money," she told *Fairplay*.

Those vessels that are operating in a strong market will have even less incentive to reduce their speeds, with Lindstad pointing out that vessels operating in such a market usually speed up on their ballast legs to secure more cargoes.

Effects of slow steaming on a 63,000 dwt Supramax

Notes: Data based on 183 days of sailing per year.
Calculations include additional power required for real sea conditions.
Source: Elisabeth Lindstad

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THANK YOU !

Dr. Elizabeth Lindstad

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