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Environmental and economic analysis of alternative powering options for coastal vessels with respect to future emission reduction targets

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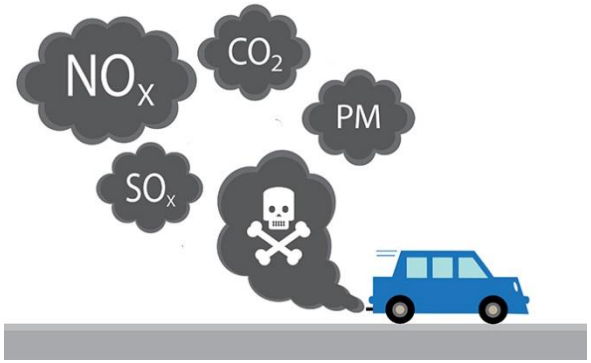
Introduction

➢ Research background

Fossil fuel combustion causes exhaust gas that comprises of:

- ✓ nitrogen oxides (NO_X)
- ✓ sulphur oxides (SO_X)
- ✓ particulate matter (PM)
- ✓ carbon monoxide (CO)
- ✓ greenhouse gases (GHGs): carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and fluorinated gases in low concentration.

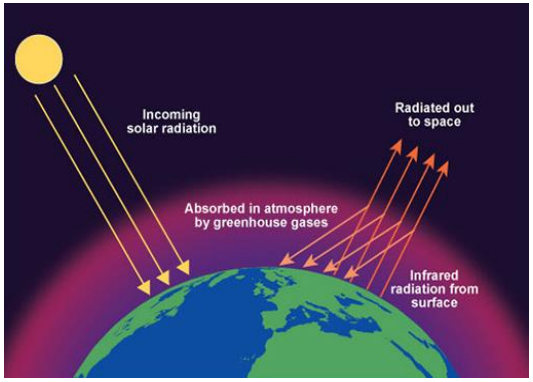


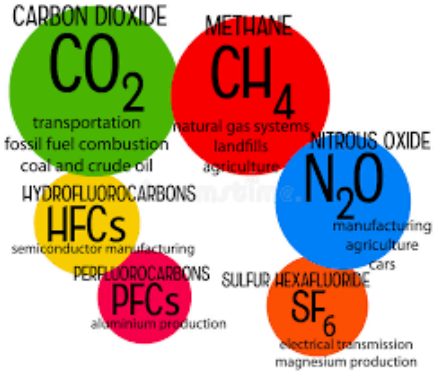
Introduction

➢ Research background

Global warming problem

- ✓ Caused by GHGs
- ✓ CO_2 is the main GHGs

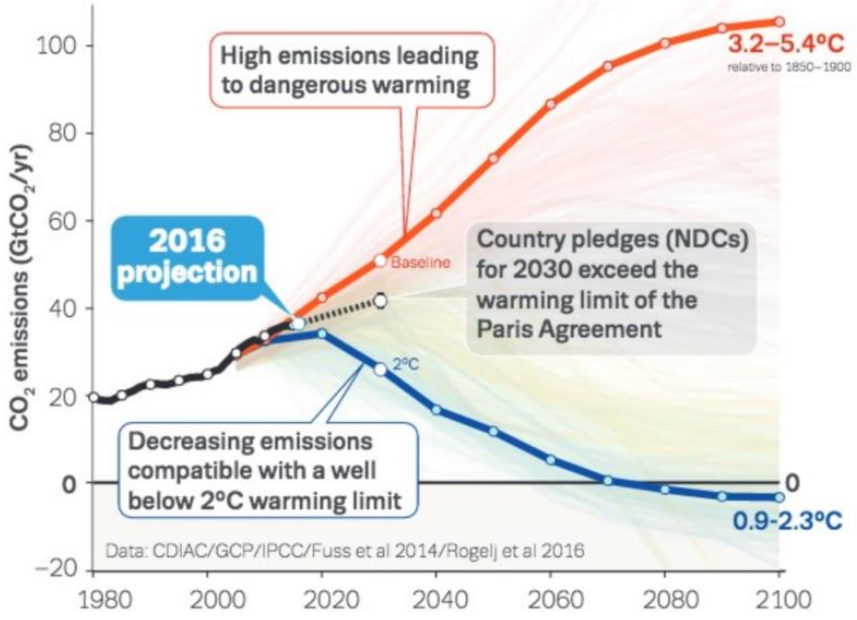




Paris Agreement

The aim:

- ✓ To keep the global temperature rise well below 2°C above preindustrial levels and preferably below 1.5°C.
- ✓ To stabilise the temperature at the desired level, a sharp decrease of CO_2 emissions is required and possibly including negative CO_2 emissions after 2080



Introduction

➢ Research background

Emission control in the shipping sector

The International Maritime Organization (IMO) established Emission Control Areas (ECAs), where emissions limitations are stricter than elsewhere

✓ **SO_X emissions** are controlled by setting the limit on sulphur content in a fuel

Date	Sulfur Limit in Fuel (% m/m)	
	SOx ECA	Global
2000	1.5%	4.5%
2010.07	1.0%	
2012		3.5%
2015	0.1%	
2020		0.5%

✓ **NO_X emissions** limits are set for diesel engines depending on an engine maximum speed

Tier	Date	NOx Limit, g/kWh		
		n < 130	130 ≤ n < 2000	n ≥ 2000
Tier I	2000	17.0	$45 \cdot n^{-0.2}$	9.8
Tier II	2011	14.4	$44 \cdot n^{-0.23}$	7.7
Tier III	2016†	3.4	$9 \cdot n^{-0.2}$	1.96

† In NOx Emission Control Areas (Tier II standards apply outside ECAs).

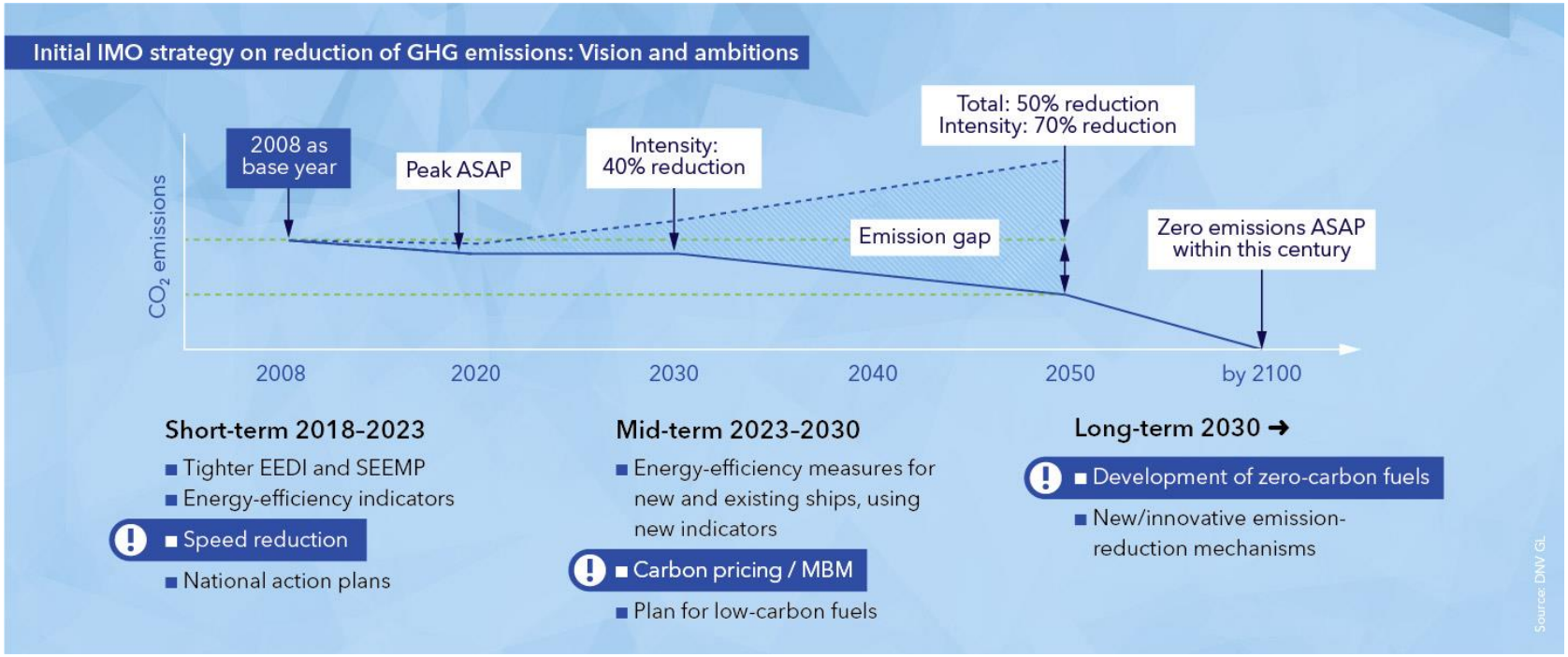
✓ **CO_2 emissions** are regulated by the Energy Efficiency Design Index

Introduction

➢ Research background

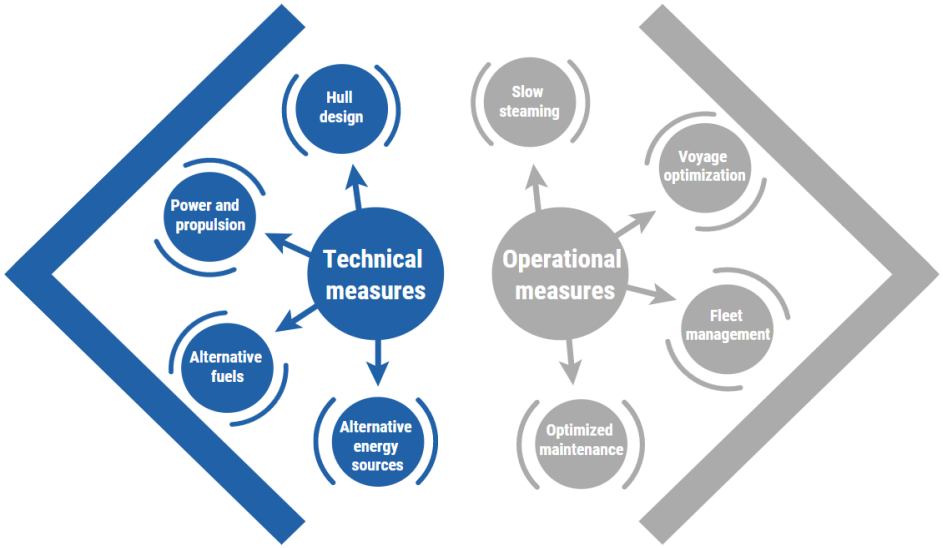
Emission reduction targets

- ✓ **GHG emissions**: reduction of annual GHGs emissions from international shipping by at least 50% by 2050, compared to 2008 level
- ✓ **CO_2 emissions:** reduction of average carbon intensity (CO_2 per ton-mile) by a minimum 40% by 2030, and 70% before 2050, compared to 2008 level.



State-of-the-art

➢ Decarbonization measures in shipping sector



	Saving of CO_2/tonne-mile	Combined	Combined
DESIGN (New ships)			
Concept, speed and capability	2% to 50%†		
Hull and superstructure	2% to 20%		
Power and propulsion systems	5% to 15%	10% to 50%+	
Low-carbon fuels	5% to 15%*		
Renewable energy	1% to 10%		25% to 75%+
Exhaust gas CO_2 reduction	0%		
OPERATION (All ships)			
Fleet management, logistics & incentives	5% to 50%+		
Voyage optimization	1% to 10%	10% to 50%+	
Energy management	1% to 10%		

* CO_2 equivalent, based on the use of LNG.
† Reductions at this level would require reductions of operational speed.

State-of-the-art

➢ Decarbonization measures

Alternative powering options

✓ Implementation of RESs on board ships



✓ Implementation of alternative cleaner fuels in ship power systems

✓ Implementation of hybrid ship power systems

State-of-the-art

✓ The electrification of ships 

Fully electric	Plug-in Hybrid	Hybrid
• Battery as the primary power source • The absence of diesel fuel and emissions • Suitable for short-sea shipping vessels • Battery is charged with shore power	• Battery powers the ship in specific operations • Reduction of emissions and fuel consumption • Suitable for long haul ferries and workboats • Batteries are charged with shore power and excess energy generated from engine	• Battery absorbs load variations, so that engines only see the average system load • Improvement of fuel efficiency, reduction of engine hours and low load operations • Batteries are recharged using excess engine energy

Methodology

➢ Technical analysis

✓ The analysis is focused on the energy needs and environmental impact of the Croatian short-sea shipping fleet

1. • Fleet's schedule analysis
2. • Average speed calculation
3. • Energy needs analysis
4. • Calculation of a ship average power and fuel consumption
5. • Tailpipe emissions calculation

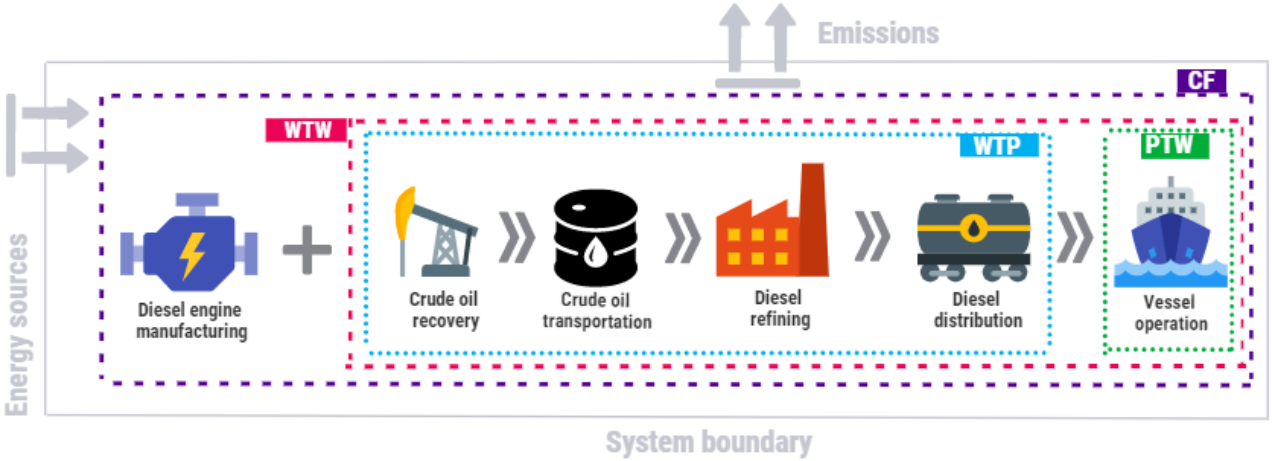
Methodology

➢ Environmental analysis

Life-Cycle Assessment (LCA)

Environmental assessment that considers emissions released through the life-cycle of a ship power system.

- ✓ **WTP (Well-to-Pump) emissions**
- ✓ **PTW (Pump-to-Wake) emissions**
- ✓ **Manufacturing emissions**



Methodology

➢ Economic analysis

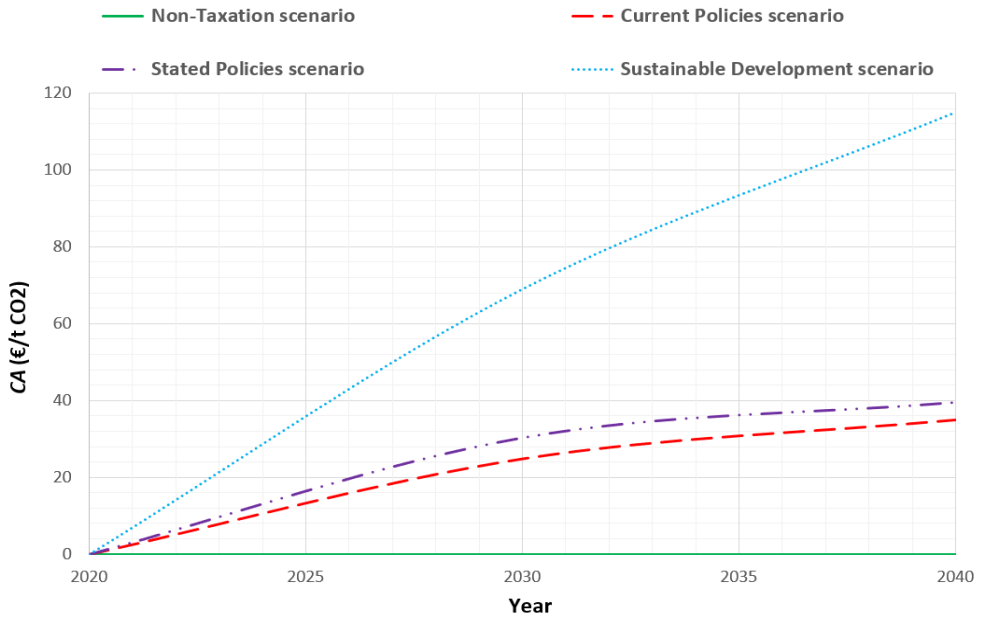
Life-Cycle Cost Assessment (LCCA)

Economic analysis that considers total costs related to the power system through the lifetime of a ship

Total costs

- **Investment cost**
- **Exploitation costs**
  - Fuel cost
  - Maintenance cost
  - Carbon emission cost

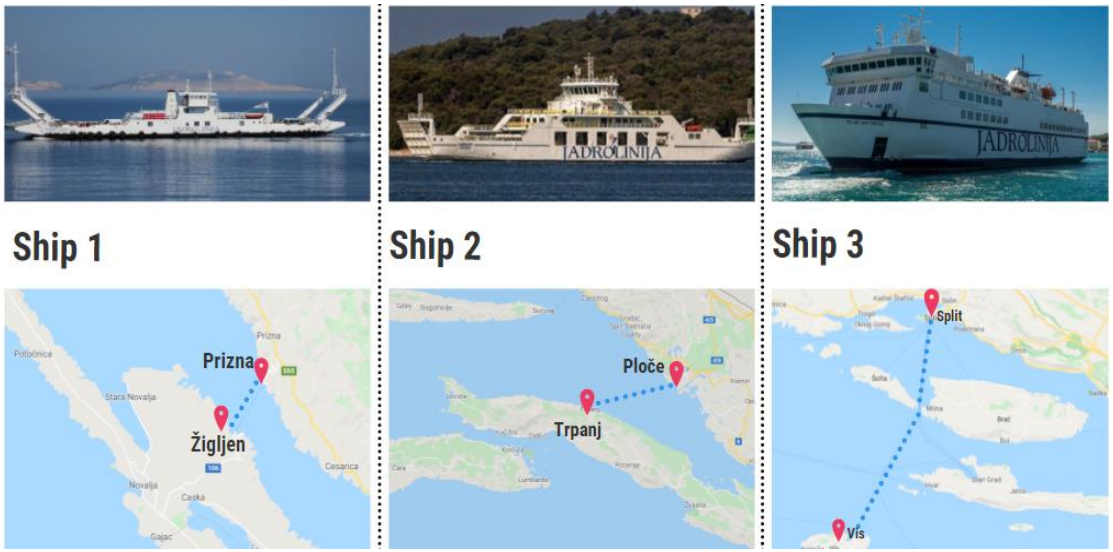
Carbon tax



Illustrative examples

➢ Short-sea shipping sector-Case study of Croatia

✓ The analysis of alternative powering options is performed on three different ship engaged in the Croatian short-sea shipping fleet.



Illustrative examples

➢ The electrification of ships

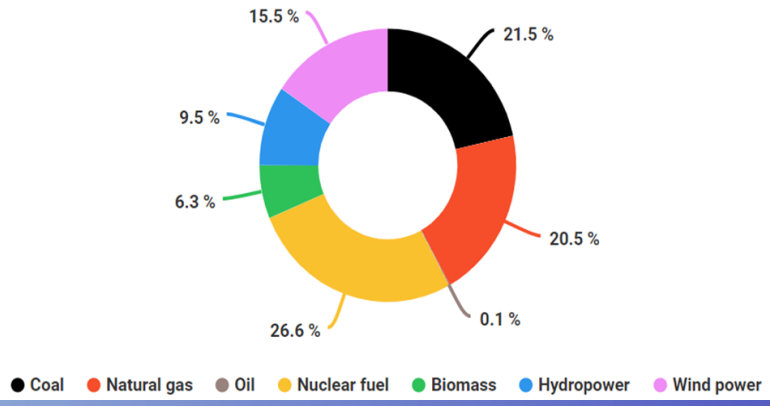
Fully electric ship

- ✓ Available and familiar battery technology
- ✓ High investment cost
- ✓ Limited range of a trip

Commercially available and investigated batteries for shipping purpose are:

- ✓ **Lead-acid battery**
- ✓ **Nickel-metal hydride battery**
- ✓ **Lithium-ion battery**

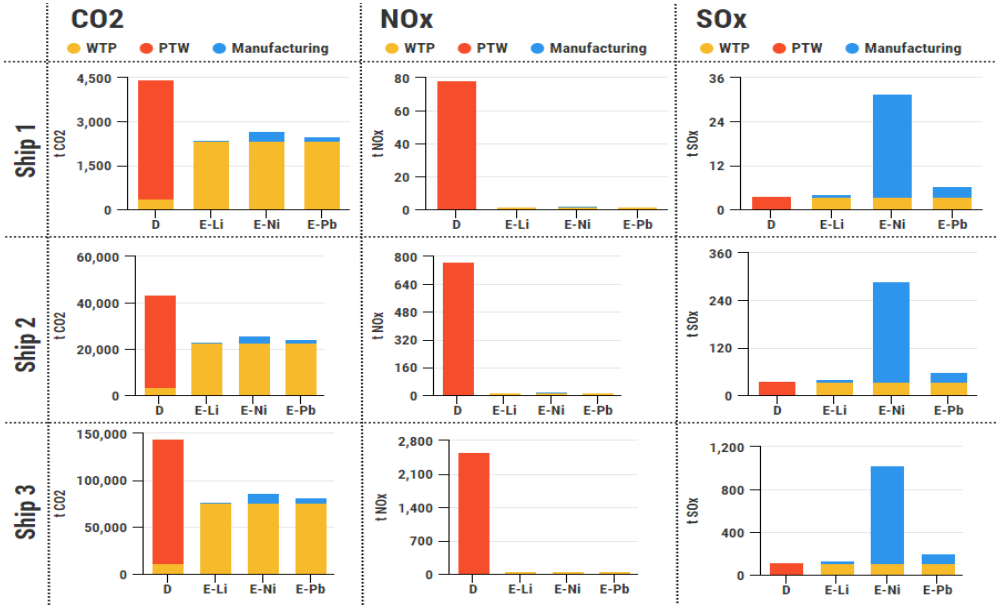
- ✓ Life-cycle emissions of the fully electric ships mostly depend on the electricity mix used



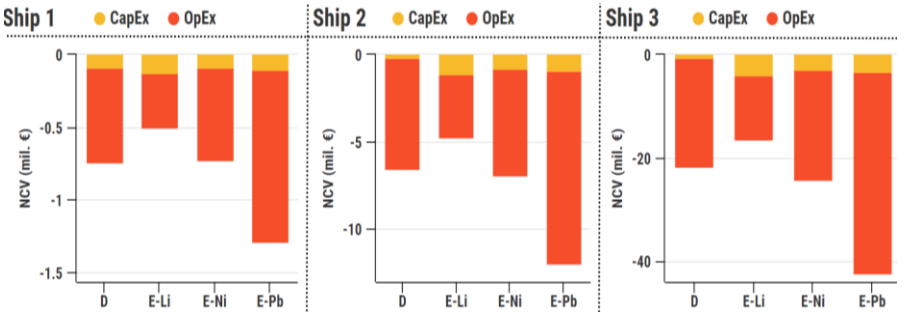
Illustrative examples

➢ The electrification of ships

✓ **LCA**



✓ **LCCA**



Li-ion battery is the most cost-effective and the most ecological battery for marine applications!

Illustrative examples

➢ Alternative powering options

Different ship power systems: implementation of RESs

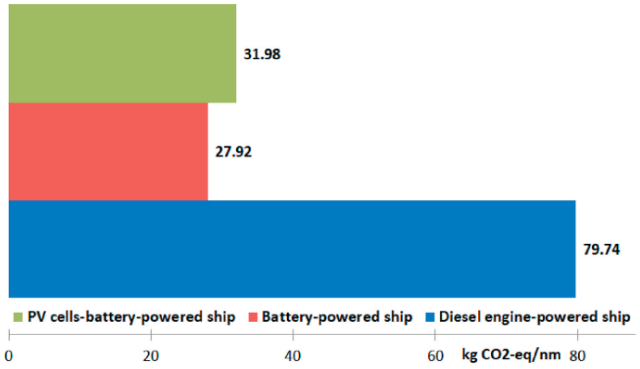
✓ **Fully electrification with battery and PV cells**

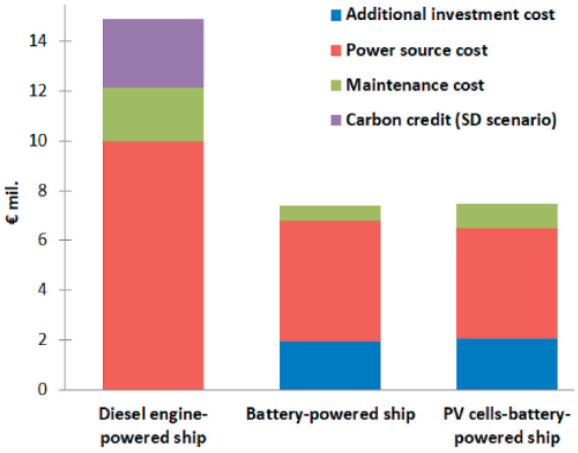
Different alternative marine fuels: cleaner fuels with lower carbon content

- ✓ **Electricity**
- ✓ **Methanol**
- ✓ **Natural gas (LNG, CNG)**
- ✓ **Dimethyl ether**
- ✓ **Hydrogen**
- ✓ **Biodiesel-diesel blend (B20)**

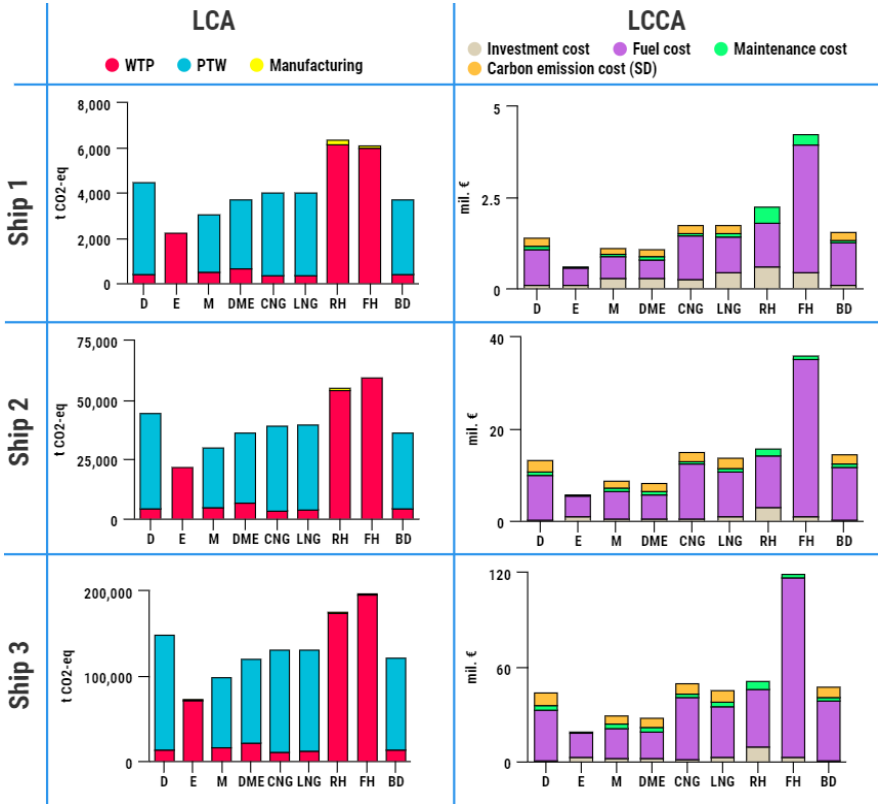
Illustrative examples

✓ Different ship power systems





✓ Different marine fuels



Full electrification is the most environmentally friendly and cost-efficient solution for emission reduction!!

Conclusion

- Full electrification of ships represents the most effective option to reduce the shipping emissions.
- Currently, the most prominent battery for shipping purposes is the Li-ion battery.
- Further development of the battery technology (metal-air batteries) will results with the electrification of the long-distance ships.

Limitations

- The study considered application of single powered source per ship power system, but not their combintations simultaneously (leading to hybrid power system configurations).

Future / ongoing investigations

- Design of optimal power system for a pre-defined set of key performance indicators (KPIs) like: allowable emissions, required operative parameters (ship speed and capacity), economic indicators, etc., through multi-criterial optimization procedure (application of ModeFRONTIER software) – more details expected to be shown in an SI journal paper.

Thanks for Your Attention!!!

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