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

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Contents

➢ INTRODUCTION

➢ STATE-OF-THE-ART

➢ METHODOLOGY

➢ ILLUSTRATIVE EXAMPLES

➢ CONCLUSION
Introduction

➢ Research background

Fossil fuel combustion causes exhaust gas that comprises of:
✓ nitrogen oxides (NOx)
✓ sulphur oxides (SOx)
✓ particulate matter (PM)
✓ carbon monoxide (CO)
✓ greenhouse gases (GHGs): carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O) and fluorinated gases in low concentration.
Introduction

➢ Research background

Global warming problem
✓ Caused by GHGs
✓ CO₂ 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 CO₂ emissions is required and possibly including negative CO₂ 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\textsubscript{X} emissions** are controlled by setting the limit on sulphur content in a fuel

<table>
<thead>
<tr>
<th>Date</th>
<th>Sulfur Limit in Fuel (% m/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SO\textsubscript{X} ECA</td>
</tr>
<tr>
<td>2000</td>
<td>1.5%</td>
</tr>
<tr>
<td>2010.07</td>
<td>1.0%</td>
</tr>
<tr>
<td>2012</td>
<td>0.1%</td>
</tr>
<tr>
<td>2015</td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td></td>
</tr>
</tbody>
</table>

✓ **NO\textsubscript{X} emissions** limits are set for diesel engines depending on an engine maximum speed

<table>
<thead>
<tr>
<th>Tier</th>
<th>Date</th>
<th>NO\textsubscript{x} Limit, g/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>n &lt; 130</td>
</tr>
<tr>
<td>Tier I</td>
<td>2000</td>
<td>17.0</td>
</tr>
<tr>
<td>Tier II</td>
<td>2011</td>
<td>14.4</td>
</tr>
<tr>
<td>Tier III</td>
<td>2016†</td>
<td>3.4</td>
</tr>
</tbody>
</table>

† In NO\textsubscript{x} Emission Control Areas (Tier II standards apply outside ECAs).

✓ **CO\textsubscript{2} emissions** are regulated by the Energy Efficiency Design Index
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
✓ **CO₂ emissions**: reduction of average carbon intensity (CO₂ per ton-mile) by a minimum 40% by 2030, and 70% before 2050, compared to 2008 level.
Decarbonization measures in shipping sector

<table>
<thead>
<tr>
<th>DESIGN (New ships)</th>
<th>Saving of CO₂/tonne-mile</th>
<th>Combined</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept, speed and capability</td>
<td>2% to 50%*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hull and superstructure</td>
<td>2% to 20%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power and propulsion systems</td>
<td>5% to 15%</td>
<td>10% to 50%*</td>
<td></td>
</tr>
<tr>
<td>Low-carbon fuels</td>
<td>5% to 15%*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Renewable energy</td>
<td>1% to 10%</td>
<td></td>
<td>25% to 75%*</td>
</tr>
<tr>
<td>Exhaust gas CO₂ reduction</td>
<td>0%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| OPERATION (All ships)                              |                          |          |          |
| Fleet management, logistics & incentives           | 5% to 50%*                |          |          |
| Voyage optimization                               | 1% to 10%                 | 10% to 50%* |          |
| Energy management                                 | 1% to 10%                 |          |          |

* CO₂ 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
- 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

### Plug-in Hybrid
- 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

### Hybrid
- 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
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**

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**Carbon tax**

- Non-Taxation scenario
- Current Policies scenario
- Stated Policies scenario
- Sustainable Development scenario

**CA (€/tCO2)**

- 0
- 20
- 40
- 60
- 80
- 100
- 120

**Year**

- 2020
- 2025
- 2030
- 2035
- 2040

- Fuel cost
- Maintenance cost
- Carbon emission cost
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
The electrification of ships

- **LCA**
  - CO2 emissions
  - NOx emissions
  - SOx emissions

- **LCCA**
  - Capital expenditure (CapEx)
  - Operating expenditure (OpEx)

Li-ion battery is the most cost-effective and the most ecological battery for marine applications!
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)
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 result in the electrification of the long-distance ships.

Limitations

➢ The study considered application of single powered source per ship power system, but not their combinations 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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