IMO 3rd GHG Study
To IMO MEPC, 14th October, London
Contents

• International shipping’s CO$_2$ emissions 2007-2012
• Inventory method and detailed results
• Inventory results for non-CO$_2$ emissions
• Scenarios for future emissions
Inventory of international shipping’s emissions
Global CO₂ and economy trends

Shipping is a small fraction (2-3%) of global CO₂. But it contributes similar amounts as major nations. So, let’s transform into an index to compare trends.
Global CO$_2$ and economy trends

All cited in the IMO GHG Study 2014
Global CO$_2$ and economy trends

- First IMO GHG Study (top-down fuel statistics)
- Second IMO GHG Study (consensus activity-based)
- Third IMO GHG Study

Global CO$_2$ Emissions, IPCC, World GDP, IMO Studies: CO$_2$
Activity-based methods preferred

Flowchart based on Decision Tree(s) for estimating mobile source emissions;
2006 IPCC Guidelines for Greenhouse Gas Inventories,
Uncertainty provides an upper estimate of adjusted total international bunkers. This allows for the quantification of uncertainty in top-down marine fuel statistics for the first time. Two key sources of uncertainty are:

1. Sector misallocations: \( \text{Exports}_{\text{World}} \neq \text{Imports}_{\text{World}} \)

2. Transfers reporting errors/omissions: \( T_{\text{out}} \neq T_{\text{in}} \)
Top-down and bottom-up results
IMO Study 2009 and 2014, international shipping

Year 2007 best-estimates for both IMO Study 2009 and 2014 are in close agreement; greater differences between bottom-up and top-down than between studies.
Activity model results are compared against noon-report data.
Fuel consumption, all ship types by engine/boiler, 2012 (bottom-up method)

<table>
<thead>
<tr>
<th>Ship Type</th>
<th>Main Engine</th>
<th>Auxiliary Engine</th>
<th>Boiler</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yacht</td>
<td>1,100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle</td>
<td>7,900</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Service - tug</td>
<td>6,700</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Service - other</td>
<td>3,800</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ro-Ro</td>
<td>9,300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refrigerated bulk</td>
<td>5,700</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other liquids tankers</td>
<td>300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oil tanker</td>
<td></td>
<td>39,700</td>
<td></td>
</tr>
<tr>
<td>Offshore</td>
<td></td>
<td>8,600</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous - other</td>
<td>2,300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Miscellaneous - fishing</td>
<td></td>
<td>16,100</td>
<td></td>
</tr>
<tr>
<td>Liquefied gas tanker</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General cargo</td>
<td></td>
<td>15,700</td>
<td></td>
</tr>
<tr>
<td>Ferry-RoPax</td>
<td></td>
<td>9,900</td>
<td></td>
</tr>
<tr>
<td>Ferry-pax only</td>
<td>3,700</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cruise</td>
<td></td>
<td>11,100</td>
<td></td>
</tr>
<tr>
<td>Container</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical tanker</td>
<td></td>
<td>17,500</td>
<td></td>
</tr>
<tr>
<td>Bulk carrier</td>
<td></td>
<td>53,400</td>
<td></td>
</tr>
</tbody>
</table>

*Corbett, Smith, Anderson 2014*
CO$_2$ emissions, international shipping, 2007-2012 (bottom-up method)
Container ship annual main engine consumption

![Box plot showing container ship annual main engine consumption](image-url)
Dry bulk trends (2007-12)

Fleet total dwt capacity

Average dwt

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Dry bulk trends (2007-12)

- Fleet total dwt capacity
- Average dwt
- Demand tonne-miles
- Fleet total CO2 emissions

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The graph compares the ratio of operating to design speed (%), main engine output (%MCR), and average daily fuel consumption for different types of ships in 2007 and 2012.

- **5000-7999 TEU container**
  - 2007: 0.92
  - 2012: 0.65
- **60000-99999 dwt bulker**
  - 2007: 0.85
  - 2012: 0.78
- **80000-119999 dwt tanker**
  - 2007: 0.75
  - 2012: 0.80

**Bar Graph Details**
- **Red Bar**: Average daily fuel consumption
- **Blue Bar**: Ratio of operating to design speed (%)
- **Green Bar**: Main engine output (%MCR)

**Legend**
- 5000-7999 TEU container
  - 2007: 0.92
  - 2012: 0.65
- 60000-99999 dwt bulker
  - 2007: 0.85
  - 2012: 0.78
- 80000-119999 dwt tanker
  - 2007: 0.75
  - 2012: 0.80

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Inventory results for non-CO$_2$ emissions
## Emission factor (EF) sources

<table>
<thead>
<tr>
<th>Substance</th>
<th>Source</th>
</tr>
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<tbody>
<tr>
<td>CO(_2)</td>
<td>MEPC 63/23, Annex 8</td>
</tr>
<tr>
<td>NO(_x)</td>
<td>ENTEC 2002 for Tier 0; IMO Annex 6 Standards Tiers I-II; LNG – Kristensen 2012; Gas Turbine &amp; Steam Engines – IVL 2004</td>
</tr>
<tr>
<td>PM*</td>
<td>EPA 2007; LNG – Kristensen 2012; Gas Turbine &amp; Steam Engines – IVL 2004</td>
</tr>
<tr>
<td>N(_2)O</td>
<td>EPA 2014; LNG – Kunz &amp; Gorse 2013</td>
</tr>
<tr>
<td>CH(_4)</td>
<td>IVL 2004; LNG – MARINTEK 2010</td>
</tr>
<tr>
<td>NMVOC</td>
<td>ENTEC 2002; LNG – Kristensen 2012</td>
</tr>
</tbody>
</table>

- LNG emission factors based on Otto cycle engines
- Fuel sulphur content taken from IMO sulphur monitoring reports. Geographical limits of ECAs taken from IMO documentation and applied accordingly.
- Non-combustion related emissions follow the methods described in IMO Study 2009
Other Greenhouse Gases

• 2007-2012 changes in estimated international shipping CH$_4$, N$_2$O, & CO$_2$ emissions
Other Relevant Substances

• 2007-2012 changes in estimated international shipping SOx, NOx, & CO₂ emissions
Scenarios for future emissions
Emissions projection

- 2nd IMO GHG Study projected rapid emissions increase
- Since it’s publication
  - A new set of long-term socio-economic scenarios has been developed by IPCC
  - Larger and more efficient container ships have entered the market
  - New emission projection methods have been developed,
    - Based on transport work activity, rather than tonnes of cargo
    - Taking into account non-linear relations between activity drivers (e.g. GDP) and activity (transport work)
- IMO Study 2014 has developed new projections
Shipping CO₂ emissions are projected to increase by 50% to 250% in the period to 2050, despite fleet average efficiency improvements of about 40%.
Projections for other species

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Projection model

Emissions

- Emission factors
  - MARPOL
  - ECAs

- Fuel mix

- Fuel consumption

Emission factors

- Energy content
- EEDI, SEEMP

Fuel consumption

- EEDI, SEEMP
- Autonomous improvements
- Speed

Energy demand

- Autonomous improvements
- MAC curve
- Fuel prices

Fleet composition

- Transport work
- Ship size
- Fleet productivity

Transport demand

- GDP projections
- Coal and oil consumption projections
Shipping CO$_2$ emissions

Additional efficiency
40% → 60%
Thank you

for enquiries, please contact:
Inventories 2007-2012 - tristan.smith@ucl.ac.uk
Scenarios 2012-2050 – faber@ce.nl
Backup slides....
Fleet disaggregation aligned with IMO

- Combined IMO Study 2009 and EEDI ship type definitions
- Size categorisations consistent with IMO Study 2009

Fleet definition:

- In-active
- <300GT
- Present in IHSF and activity data
- AIS observed
- Domestic navigation only
- Incomplete IHSF data

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LRIT data provides independent quality check of AIS derived inputs
AIS Coverage and its agreement with LRIT estimated activity

![Graph showing the mean difference in days at sea (AIS-LRIT) and standard deviation.](image1)

![Graph showing the percentage of high reliability AIS coverage over time.](image2)
Uncertainty provides an upper estimate

Quantify uncertainty in top-down marine fuel statistics for first time

Two key sources of uncertainty:

1. Sector misallocations 
   \(\text{Exports}_{\text{World}} \neq \text{Imports}_{\text{World}}\)

2. Transfers reporting errors/omissions 
   \(\text{T}_{\text{out}} \neq \text{T}_{\text{in}}\)
Fuel type allocation remains uncertain

All ship division of fuels is similar to top-down sales ratio

International ship division of fuels suggests more HFO used

<table>
<thead>
<tr>
<th>Fuel type</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>MDO</td>
<td>23%</td>
<td>22%</td>
<td>19%</td>
<td>21%</td>
<td>21%</td>
<td>21%</td>
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<tr>
<td>HFO</td>
<td>76%</td>
<td>76%</td>
<td>79%</td>
<td>76%</td>
<td>77%</td>
<td>76%</td>
</tr>
<tr>
<td>LNG</td>
<td>1%</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
<td>3%</td>
</tr>
<tr>
<td>All fuels</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fuel type</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
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</thead>
<tbody>
<tr>
<td>MDO</td>
<td>11%</td>
<td>11%</td>
<td>12%</td>
<td>13%</td>
<td>13%</td>
<td>13%</td>
</tr>
<tr>
<td>HFO</td>
<td>88%</td>
<td>87%</td>
<td>86%</td>
<td>84%</td>
<td>85%</td>
<td>84%</td>
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<tr>
<td>LNG</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>All fuels</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
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</table>
Fuel type allocation for bottom-up method

### Million Tonnes

<table>
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<tr>
<th>Fuel type</th>
<th>International or Domestic</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
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<tbody>
<tr>
<td>HFO</td>
<td>International</td>
<td>248</td>
<td>258</td>
<td>237</td>
<td>209</td>
<td>230</td>
<td>214</td>
</tr>
<tr>
<td></td>
<td>Domestic</td>
<td>18</td>
<td>19</td>
<td>11</td>
<td>15</td>
<td>20</td>
<td>13</td>
</tr>
<tr>
<td>MDO</td>
<td>International</td>
<td>30</td>
<td>32</td>
<td>33</td>
<td>32</td>
<td>34</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Domestic</td>
<td>50</td>
<td>48</td>
<td>28</td>
<td>30</td>
<td>34</td>
<td>32</td>
</tr>
<tr>
<td>LNG</td>
<td>International</td>
<td>5</td>
<td>6</td>
<td>5</td>
<td>7</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Domestic</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>All fuels</td>
<td></td>
<td>351</td>
<td>363</td>
<td>314</td>
<td>293</td>
<td>326</td>
<td>300</td>
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</table>

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Top-down CO₂ estimates

<table>
<thead>
<tr>
<th>Marine Sector</th>
<th>Fuel Type</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
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<tbody>
<tr>
<td></td>
<td>HFO</td>
<td>542.1</td>
<td>551.2</td>
<td>516.6</td>
<td>557.1</td>
<td>554.0</td>
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<tr>
<td>International shipping</td>
<td>MDO</td>
<td>83.4</td>
<td>72.8</td>
<td>79.8</td>
<td>90.4</td>
<td>94.9</td>
</tr>
<tr>
<td></td>
<td>NG</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>T-D Combined</td>
<td>625.5</td>
<td>624.0</td>
<td>596.4</td>
<td>647.5</td>
<td>648.9</td>
</tr>
<tr>
<td>Top-down International Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>HFO</td>
<td>62.0</td>
<td>44.2</td>
<td>47.6</td>
<td>44.5</td>
<td>39.5</td>
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<tr>
<td>Domestic navigation</td>
<td>MDO</td>
<td>72.8</td>
<td>76.6</td>
<td>75.7</td>
<td>82.4</td>
<td>87.8</td>
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<tr>
<td></td>
<td>NG</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>T-D Combined</td>
<td>134.9</td>
<td>121.0</td>
<td>123.4</td>
<td>127.1</td>
<td>127.6</td>
</tr>
<tr>
<td>Top-down Domestic Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fishing</td>
<td>HFO</td>
<td>3.4</td>
<td>3.4</td>
<td>3.1</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>MDO</td>
<td>17.3</td>
<td>15.7</td>
<td>16.0</td>
<td>16.7</td>
<td>16.4</td>
</tr>
<tr>
<td></td>
<td>NG</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>T-D Combined</td>
<td>20.8</td>
<td>19.2</td>
<td>19.3</td>
<td>19.2</td>
<td>19.0</td>
</tr>
<tr>
<td>Top-down Fishing Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Fuels Top-down</td>
<td></td>
<td>781.2</td>
<td>764.1</td>
<td>739.1</td>
<td>793.8</td>
<td>795.4</td>
</tr>
</tbody>
</table>

Top-down statistics report ZERO natural gas in international bunkers; we know that natural gas IS used aboard international ships.
Top-down and bottom-up results
IMO Study 2009 and 2014, all shipping

Year 2007 best-estimates for both IMO Study 2009 and 2014 are in close agreement; greater differences between bottom-up and top-down than between studies.
Top-down and bottom-up results
IMO Study 2009 and 2014, international shipping

Year 2007 best-estimates for both IMO Study 2009 and 2014 are in close agreement; greater differences between bottom-up and top-down than between studies
Uncertainty quantification, top-down and bottom-up

All ships

International ships

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IMO Study 2014 and IMO Study 2009 top-down and bottom-up comparisons

All ships

International ships

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Improved activity data has reduced uncertainty, key uncertainties quantified

**Bottom-up method impacts of uncertainty on CO₂ inventories**

- **Activity estimates**
  - Speed
  - Days at sea
- **Fleet data**
  - Number of ships in-service / laid up
  - Ship technical specification (e.g. auxiliary engine and boiler)
- **Fuel type used (HFO, LSFO, LNG and MDO)**
- **Allocation to international / domestic**

<table>
<thead>
<tr>
<th>Activity</th>
<th>2009 study</th>
<th>2014 study</th>
<th>Included in uncertainty analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity estimates</td>
<td>High</td>
<td>Low</td>
<td>Yes</td>
</tr>
<tr>
<td>Fleet data</td>
<td>High</td>
<td>Med</td>
<td>Yes</td>
</tr>
<tr>
<td>Fuel type</td>
<td>Low</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Allocation</td>
<td>High</td>
<td>High</td>
<td>No</td>
</tr>
</tbody>
</table>

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Comparisons can be understood using activity-based data

Similarities

Differences

Correlation across vessel types confirms general validity; explains differences

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## Explanation of differences

<table>
<thead>
<tr>
<th>Difference</th>
<th>Source</th>
<th>2014 Study</th>
<th>2009 Study</th>
<th>Overall effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days at sea</td>
<td>Data and method</td>
<td>Uses quarterly IHSF status indicator to indicate if laid up for part of the year</td>
<td>Annual IHSF status indicator only</td>
<td>Minor decrease in emissions</td>
</tr>
<tr>
<td>At sea main engine MCR</td>
<td>Data and method</td>
<td>Uses AIS data extrapolation, quality checked using LRIT and noon reports</td>
<td>AIS informed expert judgment</td>
<td>Minor increase in emissions</td>
</tr>
<tr>
<td>Auxiliary</td>
<td>Data and method</td>
<td>Aux power outputs derived from vessel boarding data and applied specific to mode of operation</td>
<td>Expert judgment annual aggregates</td>
<td>Minor increase in emissions</td>
</tr>
</tbody>
</table>
Specific Fuel Oil Consumption (SFOC) and Emission Factor (EF) sources

- Reference SFOC for engines, by year and type, are taken from IMO Study 2009
- Baseline SFOC for EF $g/g$ calculations:
  - ENTEC 2002; IVL 2004; LNG - Wärtsilä

- All EFs start as energy-based ($g/kWh$) then converted to fuel-based ($g/g$ of fuel)
  - EFs in $g/kWh$ divided by the associated baseline SFOC also in $g/kWh$ to get $g$ pollutant/$g$ fuel

- EFs are provided by engine type (main/aux, engine speed, NO$_x$ tier, technology)

- EFs are adjusted for fuel types and engine load
  - Fuel correction factors used to estimate any fuel type/sulphur content combination (ECA & IMO annual sulphur contents)
Other Relevant Substances

- 2007-2012 changes in estimated international shipping SOx emissions, avg fuel sulfur content, & CO$_2$ x FSC

Report pg 62 Table 16; pg 125 Table 43; pg 138 Table 63

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