Method for assessing the carbon footprint of maritime freight transport: European case study and results

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Purpose and objectives

- Quantify the contribution of maritime freight to the carbon footprint of transports and logistics operations in « standard » supply chains
- Identify possible logistics choices
- Propose feasible options for action
- Clarify some points for the calculation method of GHG in freight transport
- Contribute to GHG data collection and survey method debates for maritime freight
Research approach: a process

1. Set up the model
2. Refine existing methods for international use in Europe
3. Collect data for ‘standard’ cases
4. Findings: Calculate the results
5. Analyse the outcomes and the impacts
Set the main indicators

• Supply chain energy efficiency: Gram of oil equivalent, related to kg of product (goe/kg)
• Supply chain GHG efficiency: Gram of CO$_2$ equivalent, related to kg of product (gCO$_2$e/kg)
• Transport GHG intensity: Gram of CO$_2$ equivalent per transport performance of the vessel in tonne-kilometre (gCO$_2$e/tkm)
Energy and GHG of maritime freight: collected data (set limits of the system)

- **Operators**: Shipping lines
- **Origins, destinations, itineraries**
  - Port of origin
  - Transit and intermediate port calls
  - Port of destination
- **Time**: Days at sea & in ports
- **Distance** in nautic miles for each vessel and intermediate trip
- **Vessels**: Name and data of the vessels
  - Nominal capacity in TEU
  - Heavy fuel consumption per day at sea and in port
- **Mean load on this line**
  - Load factor of the container vessels in % of their nominal capacity
  - Mean weight of the load of one TEU
Conversion and emission factors for heavy fuel oil

<table>
<thead>
<tr>
<th>Energy equivalent</th>
<th>Emission factors</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Combustion only</td>
<td>Combustion +upstream</td>
</tr>
<tr>
<td>Fuel</td>
<td>=gCe =gCO₂e</td>
<td>=gCe =gCO₂e</td>
</tr>
<tr>
<td>HFO</td>
<td>952 859 3 153</td>
<td>968 3 553</td>
</tr>
<tr>
<td>HFO</td>
<td>1</td>
<td>3.73214</td>
</tr>
</tbody>
</table>

Source: Ademe 2007, DGEMP 2003
Supply chain model for container vessels

\[ E_i = \left( \frac{\left( (F_s \times d_s) + (F_p \times d_p) \right) \times 1000 \times 3553}{C_{\text{max}} \times L \times Q} \right) \]

where:

- \( E_i \) = GHG emission intensity per product unit, in gCO\(_2\)e per kg
- \( F_s \) = Average fuel use (heavy fuel) from the vessel (in tonnes per day at sea, t/ds)
- \( F_p \) = Average fuel use (heavy fuel) from the vessel (in tonnes per day in ports, t/dp)
- \( d_s \) = Number of days at sea for the maritime line
- \( d_p \) = Number of days in ports for the maritime line
- \( C_{\text{max}} \) = Nominal (maximal) capacity of the vessel, in TEU
- \( L \) = Mean load factor of the observed route, loaded TEU in % of \( C_{\text{max}} \)
- \( Q \) = Mean load of one TEU of a loaded box, in kg
- 1000 = tonne to kg HFO
- 3553 = Emission factor for one kg HFO expressed in gram CO\(_2\) equivalent (system observed: combustion + upstream fuel supply)
for bulk cargo vessels

\[ Ei = \frac{Fs \times ds \times 1000 \times 3553}{Q} \]

- Where:
- \( Ei \) = GHG emission intensity per product unit, in gCO2e per kg
- \( Fs \) = Average fuel use (heavy fuel) efficiency of the vessel (in tonnes HFO per day at sea)
- \( ds \) = Number of days at sea for this maritime line
- \( Q \) = Load of the bulk cargo vessel in kg
Observed maritime trips and main routes of the global system of maritime transport

Source: Rodrigue: Maritime routes; http://people.hofstra.edu/geotrans/eng/ch5en/conc5en/maritimeroutes.html
Container vessels used for the transport of apples between Nelson (NZ), Felixstowe (UK) and Antwerp (B)

Spirit of Resolution (Nelson-Auckland)

Maersk Dunafare (Auckland-Pelabuhan)

Maersk Kuantan (Pelabuhan-Felixstowe/Antwerp)
Some calculation principles

Load (Q)  
in kg = $C_{\text{max}} \times \text{load factor} \times 10,000$

Trip fuel use per loaded TEU  
in toe = $\frac{\text{toe}}{(C_{\text{max}} \times \text{load factor})}$

Trip GHG  
in tCO$_2$e = $[(t/\text{ds} \times \text{nb ds})+(t/\text{dp} \times \text{nb dp})] \times \text{emission factor heavy fuel}$  
(Efhf = 3,555 gCO$_2$e/litre)

Energy efficiency  
in goe per tkm = $(\text{toe} \times 1,000,000) / [\text{km} \times (\text{TEU max} \times \text{load factor} / 10)]$

Energy efficiency  
in goe per kg = $(\text{toe} \times 1,000,000) / \text{kg}$

GHG intensity  
in gCO$_2$e per kg = $(\text{tCO}_2\text{e} \times 1,000,000) / \text{kg}$
Results: energy efficiency of maritime trips

Nelson-Anvers: 25754 km
Nelson-Felixstowe: 25754 km
Nelson-Sheerness: 21039 km
Itajai-Le Havre: 9677 km
Itajai-Anvers: 10886 km
Itajai-Felixstowe: 10886 km
Algeciras Anvers: 2752 km
Algeciras Felixstowe: 2752 km
Itajai Algeciras: 8114 km
Itajai Le Havre: 9677 km
Nelson Sheerness: 21039 km
Pelabuhan Felixstowe: 15142 km
Pelabuhan Anvers: 15142 km
Auckland Pelabuhan: 9440 km
Nelson Auckland: 1172 km

goe/kg

Nelson-Anvers
Nelson-Felixstowe
Nelson-Sheerness
Itajai-Le Havre
Itajai-Anvers
Itajai-Felixstowe
Algeciras Anvers
Algeciras Felixstowe
Itajai Algeciras
Itajai Le Havre
Nelson Sheerness
Pelabuhan Felixstowe
Pelabuhan Anvers
Auckland Pelabuhan
Nelson Auckland
### Table: Explaining differences & calculations

<table>
<thead>
<tr>
<th>Port of origin</th>
<th>Nelson</th>
<th>Auckland</th>
<th>Pelabuhan</th>
<th>Pelabuhan</th>
<th>Nelson</th>
<th>Nelson</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port of destination</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trip distance (km)</td>
<td>1172</td>
<td>9440</td>
<td>15142</td>
<td>25754</td>
<td>21039</td>
<td></td>
</tr>
<tr>
<td>Q=Loaded tonnes</td>
<td>2376</td>
<td>24672</td>
<td>37200</td>
<td>37200</td>
<td></td>
<td>6259</td>
</tr>
<tr>
<td>Vessel capacity (Cmax in TEU)</td>
<td>379</td>
<td>4112</td>
<td>6200</td>
<td>6200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L=Load factor (in % of Cmax)</td>
<td>60%</td>
<td>60%</td>
<td>60%</td>
<td>60%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tonnes per loaded TEU</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel use per day at sea (t/ds)</td>
<td>28</td>
<td>160</td>
<td>246</td>
<td>246</td>
<td>41,5</td>
<td></td>
</tr>
<tr>
<td>Fuel use per day in port (t/dp)</td>
<td>13</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>2,5</td>
<td></td>
</tr>
<tr>
<td>Trip: number of days at sea (nb ds)</td>
<td>2,7</td>
<td>13</td>
<td>19,7</td>
<td>19,7</td>
<td>35,4</td>
<td>27</td>
</tr>
<tr>
<td>Days in ports (nb dp)</td>
<td>6</td>
<td>2,7</td>
<td>2,7</td>
<td>11,4</td>
<td>6,5</td>
<td></td>
</tr>
<tr>
<td>Total trip fuel use (toe)</td>
<td>72</td>
<td>2058</td>
<td>4657</td>
<td>4657</td>
<td>6787</td>
<td>1083</td>
</tr>
<tr>
<td>Emissions of the trip (tCO$_2$e)</td>
<td>268,6</td>
<td>7391</td>
<td>17219</td>
<td>17219</td>
<td>24878</td>
<td>3981</td>
</tr>
</tbody>
</table>

**Emissions** = [(t/ds * nb ds)+(t/dp * nb dp)] * emission factor heavy fuel (3555 gCO$_2$e/litre)

| Fuel use per TEU (toe/TEU) | 0,316  | 0,834   | 1,252     | 1,252     | 2,403  |        |
| Fuel use per TEU = toe / (TEUmax * Load factor)

| Energy use per tkm (goe/1000km) | 27,0   | 8,8     | 8,3       | 8,3       | 9,3    | 8,2    |
| Energy efficiency in goe per tkm = (toe* 1,000,000) / [km * (TEUmax * Load factor / 10)]

| Energy supply chain (goe/kg) | 31,6   | 83,4    | 125,2     | 125,2     | 240,3  | 173    |
| Energy efficiency in goe per kg = (toe* 1,000,000) / kg

| GHG intensity (gCO$_2$e/kg) | 118    | 300     | 463       | 463       | 881    | 636    |
| GHG intensity in gCO$_2$e per kg = (tCO$_2$e * 1,000,000) / kg
# Uncertainty on load weight of one TEU

Traffic data in ports 2006

<table>
<thead>
<tr>
<th>Gross (m t)</th>
<th>% of containers</th>
<th>Traffic Tonnage (m t)</th>
<th>Containers (1000 TEU)</th>
<th>Tonnes/TEU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotterdam</td>
<td>353,6</td>
<td>21</td>
<td>74,256</td>
<td>9575</td>
</tr>
<tr>
<td>Antwerp</td>
<td>151,7</td>
<td>43</td>
<td>65,231</td>
<td>6718</td>
</tr>
<tr>
<td>Hamburg</td>
<td>115,5</td>
<td>61</td>
<td>70,455</td>
<td>8878</td>
</tr>
</tbody>
</table>

Tonnes/TEU = Containers Million Tonnes / 1000 TEU

Source (original source values are in italic)


About 10 tonnes per TEU
Results: Description of apple supply chains sold in large superstores in F, B and UK

Maritime transport
Importance of maritime freight in the observed supply chain, in gCO₂e/kg
Results: Import of drawer chest from Brazil

Maritime transport

Forest Brazil Producer  
\[\text{Port Itajai (Brazil)}\]  
\[\text{Port du Havre}\]  
\[\text{Importer Orléans}\]  
\[\text{RDC IdF deliveries}\]  
\[\text{Shop Paris}\]  
\[\text{Paris}\]

Forest Brazil Producer  
\[\text{Port Itajai (Brazil)}\]  
\[\text{Port du Havre}\]  
\[\text{Importer Orléans}\]  
\[\text{RDC IdF deliveries}\]  
\[\text{Shop Paris}\]  
\[\text{Paris}\]

Forest Brazil Producer  
\[\text{Port Itajai (Brazil)}\]  
\[\text{Port du Havre}\]  
\[\text{Importer Orléans}\]  
\[\text{RDC Limoges}\]  
\[\text{Limousin}\]

Forest Brazil Producer  
\[\text{Port Itajai (Brazil)}\]  
\[\text{Felixstowe}\]  
\[\text{NDC Northampton}\]  
\[\text{RDC London}\]  
\[\text{London}\]

Forest Brazil Producer  
\[\text{Port Itajai (Brazil)}\]  
\[\text{Felixstowe}\]  
\[\text{NDC Northampton}\]  
\[\text{RDC London}\]  
\[\text{London}\]

Forest Brazil Producer  
\[\text{Port Itajai (Brazil)}\]  
\[\text{Felixstowe}\]  
\[\text{NDC Northampton}\]  
\[\text{RDC Aberdeen}\]  
\[\text{Aberdeen}\]

Forest Brazil Producer  
\[\text{Port Itajai (Brazil)}\]  
\[\text{Antwerp}\]  
\[\text{Importer Brussels}\]  
\[\text{Brussels}\]

Forest Brazil Producer  
\[\text{Port Itajai (Brazil)}\]  
\[\text{Antwerp}\]  
\[\text{Importer Brussels}\]  
\[\text{Wallonia}\]
Case of drawer chest supply chain:
GHG emission intensity in gCO$_2$e/kg
## Maritime data for the drawer chest case

<table>
<thead>
<tr>
<th>Type of trip</th>
<th>Total trip 1</th>
<th>Ocean line</th>
<th>Line hub service</th>
<th>Total trip 2</th>
<th>Change in % Trip 1 = 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Origin</td>
<td>Itajai</td>
<td>Itajai</td>
<td>Algeciras</td>
<td>Itajai</td>
<td></td>
</tr>
<tr>
<td>Destination</td>
<td>Le Havre</td>
<td>Algeciras</td>
<td>Felixstowe</td>
<td>Felixstowe</td>
<td></td>
</tr>
<tr>
<td>Distance (km)</td>
<td><strong>9677</strong></td>
<td>8114</td>
<td>2752</td>
<td><strong>10886</strong></td>
<td>+12</td>
</tr>
<tr>
<td>Nominal capacity in TEU</td>
<td>3430</td>
<td>2824</td>
<td>2840</td>
<td>2832</td>
<td>-17</td>
</tr>
<tr>
<td>Mean load factor in %</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>0</td>
</tr>
<tr>
<td>Tonnnes /loaded TEU</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Tonnnes loaded</td>
<td>20,580</td>
<td>16,944</td>
<td>17,040</td>
<td>16,992</td>
<td>-17</td>
</tr>
<tr>
<td>t. HFO/day at sea</td>
<td>103</td>
<td>74.9</td>
<td>74.9</td>
<td>74.9</td>
<td>-27</td>
</tr>
<tr>
<td>t. HFO/day in port</td>
<td>30</td>
<td>16.3</td>
<td>16.3</td>
<td>16.3</td>
<td>-46</td>
</tr>
<tr>
<td>Speed in knots</td>
<td>14.0</td>
<td>17.7</td>
<td>18.8</td>
<td>18.0</td>
<td>+28</td>
</tr>
<tr>
<td>Days at sea</td>
<td><strong>15.5</strong></td>
<td>10.3</td>
<td>3.3</td>
<td><strong>13.6</strong></td>
<td>-12</td>
</tr>
<tr>
<td>Days in ports</td>
<td>2.9</td>
<td>2.2</td>
<td>1.8</td>
<td>4.0</td>
<td>+38</td>
</tr>
<tr>
<td>Fuel use of ship (toe)</td>
<td>1520</td>
<td>734</td>
<td>235</td>
<td>968.6</td>
<td>-36</td>
</tr>
<tr>
<td>Emissions of ship (tCO₂e)</td>
<td>5672.4</td>
<td>2738.8</td>
<td>876.0</td>
<td>3614.8</td>
<td>-36</td>
</tr>
<tr>
<td>Energy efficiency per TEU, toe/TEU</td>
<td>0.739</td>
<td>0.433</td>
<td>0.138</td>
<td>0.570</td>
<td>-23</td>
</tr>
<tr>
<td>Efficiency (koe / TEU /100km)</td>
<td>7.6</td>
<td>5.3</td>
<td>5.0</td>
<td>5.2</td>
<td>-31</td>
</tr>
<tr>
<td>Energy intensity (goe/tkm)</td>
<td>7.6</td>
<td>5.3</td>
<td>5.0</td>
<td>5.2</td>
<td>-31</td>
</tr>
<tr>
<td>GHG intensity (gCO₂e/tkm)</td>
<td><strong>28</strong></td>
<td>20</td>
<td>19</td>
<td><strong>20</strong></td>
<td>-31</td>
</tr>
<tr>
<td>Supply chain efficiency in goe/kg</td>
<td>73.9</td>
<td>43.3</td>
<td>13.8</td>
<td>57.1</td>
<td>-23</td>
</tr>
<tr>
<td>Ei = GHG efficiency in gCO₂e/kg</td>
<td>276</td>
<td>162</td>
<td>51</td>
<td>213.0</td>
<td>-23</td>
</tr>
</tbody>
</table>
Evaluation and analysis of the results

• 240 goe and 881 gCO$_2$e/kg ? Is it a lot?
• Choice of one of the longest maritime freight container route, on a heavy traffic itinerary, the quantity of CO$_2$ emitted remains high
• But these numbers are comparable to those of a consumer buying trip by car in rural France
Logistics and supply chain choices

• Objectives: improve through appropriate decisions:
  – the emission factor of the complete supply chain in gCO$_2$e/kg de produit
  – the energy efficiency of the chain in goe/kg de produit
  – the transport efficiency of the vessel in gCO$_2$e per tkm or per TEU and
  – the load factor of the 20 foot and 40 foot containers
Influence of distance

- The Nelson-Sheerness trip is far shorter (-4700km) than Nelson-Felixstowe; and the charter bulk vessel is more efficient for its emission intensity, in gCO$_2$e/tkm
- The return trip is not taken into account
- The choice of a far shorter route remains a strong influencing decision for the energy use of the maritime supply chain
Influence of the load

• Load factor: 60% is an estimate given by managers of maritime container lines

• Mean load of one TEU = 10 tonnes

• These values are bringing the results down, but seem realistic
Influence of speed

• The exact trip fuel use is not known by the line managers, only average annual values.
• If the exact influence of speed on the real trip fuel use should be determined, one would need a special test on real shipping lines operating with the same vessels on the same routes and the same load, but at different speed.
Influence of line choice and packaging

• For a logistics import manager, the choice is possible between options:
  – Itineraries
  – Shipping lines
  – Bulk vessel, chilled container, etc

• The case of the most efficient vessel, in geCO₂e/tkm, is on the line Brazil-Algeciras et Algeciras-Felixstowe, showing a higher number of km per day (and less port calls) of the hub system
Influence of the vessel

- The biggest vessels were not the most efficient one for GHG because of higher speed.
- The emission value ‘at constant speed’ have not been calculated, because of the lack of data on fuel use at real speed and reduced speed.
Influence of costs of maritime options in the logistics decisions

• The total costs of the offer remains the determining factor for logistics choices
• The costs of possible options are not very clear, but in one case, the most favourable GHG option was not the cheapest, but the one offering the best quality
HFO costs and supply chain costs

• 240 goe = 25 cl of heavy fuel = about 12 cents € for transporting 1 kg apples from NZ to Felixstowe
• The maritime fuel costs of 12 cts/kg in 2008 within:
  – 80 cts /kg of the sale price of the importer (15%)
  – 2,20 €/kg apple at the final consumer price (5,5%)
Possibles actions

- Reduce the speed of the vessels
- Include KPI criteria in the bids
- Choice of fastest routes (in days at sea)
- Set up and use hubs to reduce port calls
- CBA of potential actions
- Obtain original data on real fuel use of each vessel class at different speed, for the main routes and lines
Thank you for your attention

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