The devil is in the detail: Measuring and Regulating Carbon Emissions in Transportation

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Supply Chain
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Outline

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  • The Role of Supply Chains
  • Regulations
  • Opportunities
• Part 1: Carbon Regulated Supply Chains Project at TU/e+eSCF
  Jan Fransoo, Ton de Kok, Henny van Ooijen
• Part 2: Transport Mode Selection
  Kristel Hoen, Jan Fransoo, Geert-Jan van Houtum
• Conclusion
Why do we need greenhouse gas reduction?

"Increases in anthropogenic greenhouse gas concentrations is very likely to have caused most of the increases in global average temperatures since the mid-20th century."

The latest IPCC report is calling for a reduction of Greenhouse gases compared to 2000 by 24-40% till 2020 and 80-95% till 2050.
Greenhouse Gases (GHG): Global Warming Potential (GWP)

<table>
<thead>
<tr>
<th>Gas</th>
<th>GWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>1</td>
</tr>
<tr>
<td>CH₄ (methane)</td>
<td>21</td>
</tr>
<tr>
<td>N₂O</td>
<td>310</td>
</tr>
<tr>
<td>HFCs</td>
<td>150-11700</td>
</tr>
<tr>
<td>PFCs</td>
<td>6500-9200</td>
</tr>
<tr>
<td>SF₆</td>
<td>23900</td>
</tr>
</tbody>
</table>

GHG Gases: Gases that trap heat in the atmosphere.

The table above summarizes the Global Warming Potential (GWP) of different GHGs (GreenHouse Gas) defined by the Kyoto protocol.
Figure 2.1. (a) Global annual emissions of anthropogenic GHGs from 1970 to 2004. (b) Share of different anthropogenic GHGs in total emissions in 2004 in terms of CO$_2$-eq. (c) Share of different sectors in total anthropogenic GHG emissions in 2004 in terms of CO$_2$-eq. (Forestry includes deforestation.) (WGIII Figures TS.1a, TS.1b, TS.2b)

(Source: Intergovernmental Panel on Climate Change)

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Pressure on companies to act

1. Customers
   - Carbon footprint labeling
   - Tesco food miles
2. Stakeholder and shareholders
   - E.g., Carbon disclosure project
3. Regulations
   - Cap and trade mechanisms for emissions
   - Additional taxes on fuels
The Kyoto Protocol

- A legally binding agreement
- Adopted in 1997, entered into force in 2005
  - Annex I countries (OECD + EIT) agreed to reduce their collective greenhouse gas emissions by 5.2% from the 1990 level.
    - Represents a 29% cut.
  - 188 countries and the EEC have deposited instruments of ratification, accession, approval or acceptance.
The Kyoto Protocol
The Kyoto Protocol

- National targets:
  - 8% reduction for the EU
  - 7% for the US
  - 0% for Russia
  - -8% for Australia (permitted increase)
  - -10% for Iceland.

- Developing countries such as China & Brazil are not bound to reduce emissions by the Kyoto protocol
  - Can use the Clean Development Mechanism (CDM) to reduce GHG emissions thus creating valuable carbon assets known as CERs (Certified Emission Reductions).
Kyoto Protocol regulation mechanisms

• Emissions Trading Scheme
• Clean Development Mechanism (CDM)
  • Allows countries to implement an emission reduction project in developing countries and use the reduction in emissions in these countries as additional emission rights in their own country.
• Joint Implementation (JI)
  • Allows countries to implement an emission reduction project in other Kyoto-countries and using this emission reduction as additional emission rights.
Emissions Trading Scheme (EU – ETS)

- Cap-and-Trade mechanism
- Cap: Maximum amount of carbon emitted
- Allowance: right to emit a certain amount
- Emissions > Cap ⇒ buy allowances
- Emissions < Cap ⇒ sell allowances

- Applies to Greenhouse gases and energy-intensive production
- Will be extended to include aviation
Why bother “greenification” right now?

• Good News: In many cases green and less costly go hand in hand.
• Leading organizations typically benefit much more than the followers.
• Companies need to quantify and analyze cost- and CO₂ implications of their supply chain structures and operational policies.
What can be done?

Here is a short list:

1. Redesigning products
   - e.g. reducing weight
2. Redesigning production processes
   - e.g. reducing energy use, decreasing waste, etc
3. Redesigning packaging
4. Shifting to green suppliers
   - including energy supply-
What can be done?

5. Increasing remanufacturing efforts.
6. Better coordination and collaboration between the supply chain partners.
7. Decreasing the need for
   - distant transportation
     e.g. by working with closer suppliers
   - rapid transportation
     e.g. by relaxing unnecessarily tight service level agreements, holding more local inventory
   - unnecessary transportation
     e.g. by consolidating shipments, shipping full truck loads
Transport emissions are by far the main contributor to emissions growth...

![Graph showing emissions growth](image)

- **Source**: European Commission (2007)
......, despite substantial increases in energy efficiency......
…. with freight transport contributing about 40% to the total transport emissions

Passenger Transport, 1990-2030

- Aircraft
- Rail
- Cars and Motorcycles
- Buses

Freight Transport, 1990-2030

- Inland navig.
- Rail
- Road

Source: European Commission (2007)
Motivation

- If transportation emissions are not reduced, the transport sector will account for 100%-300% of the GHG emissions target of the UN by the year 2050.
- To be able to reduce the emissions in transport the first step is to calculate the emissions during transport!
- Our focus: carbon emissions resulting from transport
- Investigate emission reduction opportunities
Main issues regarding emissions regulations in transport

- Measurement of emissions
  - No clear detailed standards
    - GHG widely quoted, but does not contain sufficient detail and parameters are mainly US based
  - Due to widely spread outsourcing, difficult to obtain true emissions
    - Carriers have no incentive to share their fuel bills
- Impact of regulations have been studied only by economists
Part 1: Carbon Regulated Supply Chains Project

Understand impact of various regulation alternatives on the design and operation of supply chains

To assist decision makers in industry to prepare strategies for coping for upcoming regulations

To impact policy makers and public opinion on effectiveness and problems of new regulations
Methodology: parallel and coordinated case studies

• Develop measurement methodology, based on current best practices, limited to CO$_2$
• Measure carbon emissions in transport in European distribution network
• Based on options available from actual tendering process, assess feasibility of modal choice alternatives
• Evaluate optimal decision making, given realistic alternatives, under various regulation scenarios
<table>
<thead>
<tr>
<th>Method</th>
<th>Scope</th>
<th>Level of Detail</th>
<th>Date</th>
<th>Developer</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARTEMIS</td>
<td>Europe</td>
<td>Very high</td>
<td>2007</td>
<td>Funded by the EU</td>
</tr>
<tr>
<td>EcoTransIT</td>
<td>Europe</td>
<td>Medium</td>
<td>Ongoing</td>
<td>IFEU</td>
</tr>
<tr>
<td>GHG Protocol</td>
<td>World, focus on US</td>
<td>Low</td>
<td>Ongoing</td>
<td>Governments, NGO’s</td>
</tr>
<tr>
<td>NTM</td>
<td>Europe</td>
<td>High</td>
<td>Ongoing</td>
<td>Swedish non-profit organisation</td>
</tr>
<tr>
<td>STREAM</td>
<td>The Netherlands</td>
<td>Medium</td>
<td>2008</td>
<td>CE Delft</td>
</tr>
</tbody>
</table>
Carbon Measurement Methodology: NTM

- has a high level of detail (compared to GHG and EcoTransIT);
- offers the possibility to calculate the emissions based on varying levels of detail;
- offers the possibility of adding or changing parameters and values;
- is aligned with several European studies;
- is cooperating with the European Committee for Standardization (CEN) to set a standard for calculating emissions resulting from transport.

See: www.ntm.a.se
Carbon Measurement Methodology

- Difficulties
  - Still variety in numbers, even sometimes reversing the benefits
  - If detailed data are not available, assumptions appear to be quite rough, and could lead to 100-200% differences
  - Some aspects no data, e.g.:
    - Intermodal terminal usage (vertical handling)
    - Heating of products after transport (some chemicals and food intermediates)
Adjustments to “standard” NTM

- Parameters taken into account:
  - Weight
  - Distance
  - Modality type (10 road, 2 rail, 25 water, 33 air)
  - Load factor
  - Terrain factor
  - Positioning
  - Country

- Parameters added
  - Cleaning
  - Heating/refrigerating
  - Vertical handling

- Assumptions checked and adjusted
  - Load factors
  - Positioning
  - Road type
  - Rail traction type
Transport Emission Reporting and Reduction Analysis

Import transport data from Excel

File location

Browse

Import

View and update imported data

Transport data

View warnings (and correct data)

Severe warnings

Non-severe warnings
Carbon emission reduction options

- Payload increase
- Modal shift
- Intermodal transport
Results: Emissions reduction

- In all cases: reductions can be achieved while saving on costs
- Opportunities stay however far behind the objectives
  - No capacity on alternative modes
  - Service constraints too high for alternatives to be competitive
  - Networks have already been improved to a large extent
Regulation scenarios

1. Current ETS

2. Current ETS including sea transport, diesel tax and Euro-Vignette (most likely scenario)

3. Current ETS including all transport (with high emission prices)

4. Current ETS and separate transport ETS (with extremely high emission prices)
Results: Regulation scenarios

- Emissions trading not effective
- Specifically targeting road transport most effective, yet little impact on overall emissions
- Substantial impact in cost without significant impact on emissions reduction in all alternatives
Part 1 - Conclusion

- First (academic) empirical study on network-wide evaluation of carbon emissions
  - Complements carbon footprint studies (product focus)
  - Provides methodological insights
    - Robustness of aggregate measurements
- Emissions reduction and cost reduction in transport often go hand-in-hand, yet overall emissions targets appear out of reach
- Other more drastic improvements need to be sought
- Impact of current regulation designs appears to be very limited, while substantially increasing cost of transport
- May drive more local production, but then much higher (and hence politically infeasible) cost increases would be needed
Part 2: Impact of emission regulation on transport mode selection

Situation description:
Company is facing decision which transport mode to select for all transport.

Request for quotation is sent to Logistics Service Providers.

Relevant parameters:
- Lead time
- Transportation cost
- Unit emissions
Introduction

Research questions:

• How can emissions be determined for outsourced transport?
• What is the impact of emission costs on the transport mode decision?
• To what extent do different emission regulations lead to different solutions, in terms of selected mode and corresponding cost and emissions?
Literature

- Baumol and Vinod (1970)
- Bauer et al. (2009)
- Arrhenius (1896)
- Callendar (1938)
- Aldy et al. (2003)
- McKibbin and Wilcoxen (2002)
- Benjaafar et al. (2010)
- Shrivastava (2007)
- Corbett and Kleindorfer (2001)
- Cholette and Venkat (2009)
Model

- Periodic review, infinite horizon, full backordering
- Order-up-to policy (S)
- Objective function: average cost per period for a transport mode
- Decide for a mode of transport
Analysis

Emission calculations by NTM method:

• Accurate estimates for Air, Rail, Road and Water transport.
• Level of detail varies
• Calculate emission for entire vehicle (average load)
• Allocate part of the emissions to one unit of the product (volumetric weight for road and air)
Analysis

Emissions determined by:

- **Road**: Vehicle type, load factor, fuel consumption, distance, road type, total load
- **Air**: Airplane type, load factor, distance, total load
- **Rail**: emission factor (per country), terrain, weight of the train, distance
- **Water**: fuel consumption, distance, fuel emissions

- **Unit emissions**: product volume and density
Analysis

Emission-Constrained Transport Mode Selection Problem (ETMSP):

- Select the mode with the lowest average cost
- For some modes no feasible solution exists
Analysis

Emission Cost-minimization Transport Mode Selection Problem (ECTMSP):

• Select the mode with the lowest average cost
• Emission cost for which there is indifference between two modes: $c_e^*(i, j)$
Analysis

- If $e_j > e_i$ (e.g. $j$: air, $i$: road) $\implies c_j > c_i$ and $L_j < L_i$
- $c_e^*(i, j)$ is
  - increasing in $L_i - L_j$
  - decreasing in $e_j - e_i$ and $c_j - c_i$
Emission Cost-minimization Transport Mode Selection Problem:

|        | mode 1 | mode 2   | \cdots | mode $|I| - 1$ |
|--------|--------|----------|--------|-----------|
| mode 2 | $c_e^*(1, 2)$ | $-$      | $\cdots$ | $-$       |
| mode 3 | $c_e^*(1, 3)$ | $c_e^*(2, 3)$ | $\cdots$ | $-$       |
| \vdots | $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ |
| mode $|I|$ | $c_e^*(1, |I|)$ | $c_e^*(2, |I|)$ | $\cdots$ | $c_e^*(|I| - 1, |I|)$ |

These values specify the range for the preferred mode.
Numerical study

Emissions:

- Air emissions >> road emissions
- Unit carbon emissions example [kg/unit]
Numerical study

Graphical representation:
Unit cost as function of emission cost

Indifference emission cost as a function of the unit cost $c_a = 2.5, c_r = 1, c_l = 0.8, c_w = 0.6, D = 1200, L_a = 1, L_r = 3, L_t = 5, L_w = 7.5, v = 0.05, \rho = 1000, \psi = 0.2, r_h = \frac{0.25}{300}, r_p = 10r_h$
Numerical study

Graphical representation: Unit cost and density (low volume)
Numerical study

Graphical representation: Unit cost and density (high volume)
Numerical study

Comparison of transport modes (ECTMSP)

\[ c_t = 1, c_l = 0.8, c_w = 0.6, D = 800, L_a = 1, L_r = 2, L_t = \frac{10}{3}, L_w = 5, k = 2000, v = 0.05, \rho = 1000, \psi = 0.2, r_h = \frac{0.25}{300}, r_p = 10r_h. \]
Numerical study – Comparison of regulation alternatives

Comparison of solutions to the problems:

- ECTMSP
- TMSP, ETMSP (EM_{max} > 1.267)
- ETMSP (1.267 > EM_{max} > 0.889)
- ETMSP (0.889 > EM_{max} > 0.556)
Conclusion

• Effect of emission cost on mode selection is minor
• For realistic values of the emission cost, the solution of the transport mode selection problem remains the same
• Introducing an emission constraint is more effective