Decarbonizing Freight Transport: 
Review of Opportunities and Challenges

Professor Alan McKinnon 

*Kühne Logistics University*

Climate Change Advisory Council 
Dublin 
19 September 2019
Reduction in carbon intensity needed to achieve target in freight transport sector

EU 2011 CO₂ Reduction Target for Transport: 60% reduction between 1990 and 2050

Source: Smokers et al. (2017). Decarbonising Commercial Road Transport. Delft: TNO.
Leveraging freight decarbonisation parameters to achieve a 6-fold reduction by 2050

30% modal shift road to rail

*Rail improves energy efficiency by 50% and reduces carbon intensity of energy by 50%*

+ 20% improvement in routeing efficiency

+ 30% increase in loading of laden vehicles

+ 30% reduction in empty running

+ 50% increase in truck energy efficiency

+ 50% drop in carbon intensity of truck energy

80% reduction in carbon intensity

achievable even in 30 years?

may not be able meet the absolute CO₂ reduction target without restraining the growth in freight movement
CO$_2$ emission reduction profiles for European freight transport

Cumulative emissions 2015-2050: 34% lower
Peak 2015
More gradual decline

60% reduction

Peak 2030
Steep decline

60% reduction

Both meet 2011 Transport White Paper CO$_2$ reduction target

Five Sets of Decarbonisation Initiatives for Freight Transport

- Reduce Demand for Freight Transport
- Shift Freight to Lower Carbon Transport Modes
- Optimise Vehicle Loading
- Increase Energy Efficiency of Freight Movement
- Reduce the Carbon Content of Freight Transport Energy
Reduce the amount of stuff to be moved - Improve ‘*material efficiency*’

**Share economy:**

*Ownership to multiple usage*

**Circular economy:**

*Increase recycling and remanufacturing*

**Design products with less material:**

*Miniaturisation, lightweighting*

**Digitisation of physical products:**

*Convert freight *consignments into electrons*

**3D Printing:**

*Less material used and wasted, simplified supply chains*
Reduce Demand for Freight Transport

**Restructuring of supply chains**
- relocalize production / sourcing
- decentralize inventory
- reversal of key business trends
- high carbon-mitigation costs

**Fossil fuel phase-out**
- 41% of international seaborne trade (2016)

**Building renewable energy infrastructure**
- infrastructure is material- and transport-intensive

**Optimise vehicle routing**

Yields economic and environmental benefits – ‘win – win’ option
Five Sets of Decarbonisation Initiatives for Freight Transport

- Reduce Demand for Freight Transport
- Shift Freight to Lower Carbon Transport Modes
- Optimise Vehicle Loading
- Increase Energy Efficiency of Freight Movement
- Reduce the Carbon Content of Freight Transport Energy
Average carbon intensity of freight transport modes: \( gCO_2 / \text{tonne-}km \)

- Bulk Carrier vessel
- Pipeline
- Container ship
- Rail
- RoRo ferry
- Articulated truck
- Rigid truck
- Van
- Airfreight long-haul
- Airfreight short-haul

Data source: DEFRA (2017)

- Freight Mode Shift: 48%
- No Specific Measure: 15%
- Fuel Economy Improvement: 15%
- Electrification of Freight Rail: 7%
- Port Decarbonization: 7%
- Decarbonizing Fuel: 4%
- Improve vehicle utilisation: 4%

- Analysis of 158 NDCs for 185 countries
- Only 13% referred to freight transport (analysis by Sudhir Gota)

% of NDCs specifying particular green freight measures

NDC – nationally determined contribution
EU freight modal split (2017)

% of tonne-kms

Only Malta and Cyprus have lower rail share than Ireland – neither of which have a railway

Source: Eurostat
Five Sets of Decarbonisation Initiatives for Freight Transport

- Reduce Demand for Freight Transport
- Shift Freight to Lower Carbon Transport Modes
- Optimise Vehicle Loading
- Increase Energy Efficiency of Freight Movement
- Reduce the Carbon Content of Freight Transport Energy
Reduce empty running of trucks

% of domestic truck-kms run empty (2017)

Source: Eurostat

https://ec.europa.eu/eurostat/statistics-explained/index.php/Road_freight_transport_by_journey_characteristics#Empty_runnings
Availability of macro-level truck utilisation data in Europe

- % empty running
- loaded trips
  - average payload weight
  - % space utilisation
  - % weight utilisation
    - 2-dimensional view
      - floor-area coverage
    - 3-dimensional view
      - cube utilisation

Data availability:
- High
- Zero
Freight Density and the Utilization of Vehicle Carrying Capacity

- Polystyrene foam
- Refrigerator / white goods
- Passenger cars
- Parcels
- Groceries (mixed)
- Box of filled beer bottles
- Wood
- Fuel / ethanol
- Water / milk / beer
- Rubber
- Earth / soil
- Bricks
- Concrete
- Metal alloy
- Steel

Typical density (tonnes / cubic metre)

Decline in average density of freight

Optimum density to fill 40 tonne truck

Vehicles ‘cubing out’ space is the constraint

Vehicles ‘weighing out’ weight limit is the constraint
Constraints on Truck Utilisation

- Logistical cost trade-offs
- Demand fluctuations
- Uncertainty about transport requirements
- Unbalanced traffic flows
- Health and safety regulations
- Vehicle size and weight restrictions
- Unreliable delivery schedules
- Just-in-Time delivery
- Nature of packaging / handling equipment
- Limited storage capacity at destination
- Incompatibility of vehicle for back-loading
- no logistics / procurement co-ordination

- Market-related
- Regulatory
- Inter-functional
- Infrastructural
- Equipment-related
Supply Chain Collaboration

Deep decarbonisation of freight transport will require much greater sharing of logistics assets

- change in the corporate mindset
- exhaustion of internal efficiency improvements
- confirmation of legality
- new IT tools support collaborative working

Nestle – Pepsico Horizontal Collaboration in Benelux

Long term contribution of the Physical Internet to logistics decarbonisation

<table>
<thead>
<tr>
<th>1. Separate delivery operations</th>
<th>Kg CO2 / tonne</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Groupage by Logistics Provider</td>
<td>43.8</td>
</tr>
<tr>
<td>2. Groupage</td>
<td>27.3</td>
</tr>
<tr>
<td>3. Collaborative synchronisation</td>
<td>20.3</td>
</tr>
</tbody>
</table>

Source: Jacobs et al 2014

EU project: CO

Sustainable, safe and Secure supply chains

Full alignment of digital and physical supply chains

Integrated, transparent and collaborative logistics

Efficient and integrated supply chain management

Delivering and accessing new opportunities and business models

Urban logistics
Increasing truck size and weight — *within infrastructural constraints*

2 truck for 3 substitution: load consolidation → reduced energy use and emissions per tonne-km

Vehicle level analysis

% reduction in carbon intensity against baseline vehicle

25.5 m LHV – variable maximum weight limit

<table>
<thead>
<tr>
<th>44t</th>
<th>50t</th>
<th>50t</th>
<th>44t</th>
<th>50t</th>
<th>40t</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>5%</td>
<td>10%</td>
<td>15%</td>
<td>20%</td>
<td>25%</td>
</tr>
</tbody>
</table>

System level analysis

Net effect on CO₂ depends on:
- vehicle adoption rate
- induced traffic
- circuitous routing
- vehicle load factor
- freight modal shift

European studies of high capacity transport

Double-deck trailer (UK)
Five Sets of Decarbonisation Initiatives for Freight Transport

- Reduce Demand for Freight Transport
- Shift Freight to Lower Carbon Transport Modes
- Optimise Vehicle Loading
- Increase Energy Efficiency of Freight Movement
- Reduce the Carbon Content of Freight Transport Energy
Improve Energy Efficiency in the Freight Transport Sector

Vehicle technology: new build + retrofits

- upgraded drive-trains
- light-weighting
- low-rolling resistance tyres
- improved aerodynamics

Vehicle operation: IT, training, monitoring

eco-driver training

Telematic monitoring

Platooning

Automation

Fuel economy standards for new trucks:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan</td>
<td>Phase 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.S.</td>
<td>Phase 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td>Phase 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>Phase 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

EU: 15% less CO₂ by 2025, 30% by 2030

Source: ICCT (2015)

Factors for fuel efficiency:

- upgraded drive-trains
- light-weighting
- low-rolling resistance tyres
- improved aerodynamics

Business practice: e.g., lower vehicle speed

- 90 → 70 km/hr 12% fuel saving

Supply Chain Deceleration: *Heresy or Practical Suggestion?*

Potential for rescheduling supply chain processes to cut CO₂ emissions?

1. processing of inbound order
2. internal administration / checks
3. order picking
4. order awaiting loading
5. vehicle loading
6. vehicle waiting time
7. delivery
8. waiting time at reception point
9. vehicle off-loading and put-away
10. product storage prior to use / sale

- accelerate internal processes
- Internal time savings offset longer transit times
- net CO₂ saving within fixed order lead time

**Freight Transport Deceleration: Its Possible Contribution to the Decarbonisation of Logistics**

McKinnon (2016) *Transport Reviews*
Effects of Varying Start Times for Long Haul Road Deliveries Network

*Simulation modelling of truck trips across UK trunk road network*

Source: Palmer and Piecyk, 2010

constraints on the rescheduling of deliveries to minimize congestion
Five Sets of Decarbonisation Initiatives for Freight Transport

- Reduce Demand for Freight Transport
- Shift Freight to Lower Carbon Transport Modes
- Optimise Vehicle Loading
- Increase Energy Efficiency of Freight Movement
- Reduce the Carbon Content of Freight Transport Energy
Road Freight Transport

- increasing delivery range
- narrowing price differential
- expanding recharging network

### Local Delivery Operations
- Battery power

### Long Distance Trucking
- Battery power

#### Disagreement on Weight, Size and Recharging Time for Batteries

- **Sripad & Visvanathan, McKinsey etc**
  - 10-12 tonnes for US Class 8 truck
  - 400 kW per hour charging time

- **Bossel, Cebon etc**
  - Energy losses so high, never likely to be viable option

- **Tesla, ETC* etc**
  - 4-6 tonnes for US Class 8 truck
  - 1600 kW per hour (Tesla)

- **IDDRI, ETC* etc**
  - Despite high energy losses, still viable decarbonisation option

* Energy Transition Commission

### Hydrogen as the Energy Carrier of Low Carbon Electricity

**3rd option: Electrify the road network**

Highway electrification: the e-Highway

**Electrified roads: Trials in Sweden, Germany and the US**

- **Sweden – Operation started**
- **USA – trucks ready**
- **Germany – field trial planned**

60% of heavy truck CO₂ emissions in Germany occur on only 2% of road network.

89% of truck trips after leaving highway have a length of 50km or less.

Source: Siemens

**BDI / Boston Consulting Group / Prognos study:**

Recommends that 4000-8000 km of German autobahn network be electrified (out of 13000 km)

Capital cost of highway electrification: around €1.5 – 2.0 million per km
Uncertainty over most cost-effective energy decarbonisation pathways for trucking

What are the most cost-effective alternative energies for each type of road freight operation?

ITF/OECD (2018) expert survey

Optimum mix of decarbonisation pathways likely to vary by country
Alternative drive trains and energy sources for long haul road freight

Variation in total cost of ownership relative to fossil diesel vehicles over period 2020-2030

TCO difference compare to conventional diesel vehicle [€,2017/km]

Fuel cell
Battery electric
Overhead catenary
Synthetic fuels (PtG / PtL)

range of estimates

mean

Source: Oeko Institute, Fraunhofer ISI & IFEU
Road freight decarbonisation measures: *abatement – implementation graphs*

**Professor Cebon**

**International Energy Agency**

**Smart Freight Centre**

- 
  - High capacity transport
  - Supply chain collaboration
  - Electroformed highways
  - High capacity transport
  - Synchromodality
  - Online load matching
  - Delivery rescheduling
  - Urban freight consolidation
  - Predictive analytics
  - Down-speeding
  - Vehicle automation
  - Aerodynamic profiling
  - Biofuels
  - Physical internet
  - Low rolling resistance
  - Smart cruise control
  - Preventative maintenance
  - Nomination day delivery
  - Hybridisation
  - Vehicle telematics
  - Lightweighting
  - Remote maintenance
  - Anti-idling
  - Low rolling resistance
  - Ease of implementation

**Barriers to mainstream adoption (Technical, Economic, Political)**

- High
- Medium
- Low

**Source:** McKinnon (2018) Decarbonizing Logistics
MAC analysis for decarbonisation of articulated trucks in the UK by 2040

Decarbonising road freight

Future of Mobility: Evidence Review
Foresight, Government Office for Science
Sustainable Road Freight (SRF) Optimiser

http://www.csrf.ac.uk/srf-optimiser-2/

Source: Centre for Sustainable Road Freight
Professor Alan McKinnon

Kühne Logistics University – the KLU
Wissenschaftliche Hochschule für Logistik und Unternehmensführung
Grosser Grasbrook 17
20457 Hamburg

tel.: +49 40 328707-271
fax: +49 40 328707-109

e-mail: Alan.McKinnon@the-klu.org
website: www.the-klu.org
        www.alanmckinnon.co.uk

@alancmckinnon