9. Deep dive

Fuel Economy Policies for Heavy Duty Vehicles

Transport: Session 9 (adapted from ICCT presentation)
Jacob Teter, IEA
Jakarta, 19 July 2018

#energyefficientworld
Why policy makers should pay attention to HDVs

HDVs represent 10% of global fleet but nearly 50% of on-road GHG emissions . . . and growing

Global vehicle stock, distance traveled, and life-cycle road transport greenhouse gas emissions by vehicle type in 2015.

Projected global freight activity and life-cycle greenhouse gas emissions from 2015 to 2050.

Agenda

- Why regulate HD efficiency?
- What are the key elements of HD efficiency programs?
- Certification methodology
- Vehicle segmentation
Why regulate HD efficiency?  

Drivers for CO₂ emissions from on-road freight and market barriers
Drivers for tailpipe CO$_2$ emissions from road freight transport

CO$_2$ emissions [g CO$_2$]

- Fuel WTW carbon [g CO$_2$/MJ$_{fuel}$]
- Vehicle efficiency [MJ$_{fuel}$/veh-km]
- Freight activity [tonne-km]
- Loading factor [veh/tonne]
Life-cycle carbon intensity of different fuels

- Fuel WTW carbon \([\text{g CO}_2/\text{MJ}_{\text{fuel}}]\)
- Vehicle efficiency \([\text{MJ}_{\text{fuel}}/\text{veh-km}]\)
- CO\(_2\) emissions \([\text{g CO}_2]\)
- Freight activity \([\text{tonne-km}]\)
- Loading factor \([\text{veh/tonne}]\)


Data sources:
- European Commission proposal for recast Renewable Energy Directive to 2030;
- Valin et al. (2015);
- Searle et al. (2017);
- Malins, C. (2017)
Tractor-trailer efficiency for different regions in the year 2015

Fuel WTW carbon [g CO$_2$/MJ$_{fuel}$]

Vehicle efficiency [MJ$_{fuel}$/veh-km]

Freight activity [tonne-km]

Loading factor [veh/tonne]

Average tractor-trailer efficiency in 2015 using payloads and cycles defined for HDV certification

<table>
<thead>
<tr>
<th>Region</th>
<th>Fuel Consumption</th>
<th>Notes on cycle and payload</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan</td>
<td>2.84 km/L</td>
<td>GCVW = 38 t, Payload = 50% loading (~10 t). Cycle: JE05 (55%), 80 km/h (45%)</td>
</tr>
<tr>
<td>EU</td>
<td>33.1 L/100km</td>
<td>GCVW = 40 t, Payload = 19.3 t, Cycle: Long Haul</td>
</tr>
<tr>
<td>U.S.</td>
<td>7.3 gal/1000 ton-mi</td>
<td>GCVW = 36 t, Payload = 17.2 t, Cycle: 95% constant speed cycles</td>
</tr>
<tr>
<td>China</td>
<td>40 L/100km</td>
<td>GCVW = 40 t, 100% loading (~24 t). Cycle: C-WTVC (90% motorway)</td>
</tr>
</tbody>
</table>

* With the exception of the EU, the fuel consumption corresponds to the mandatory limits set in HDV standards. The EU vehicle efficiency is based on ICCT’s own work. The EU will propose HDV CO$_2$ standards in May 2018.
Freight activity is generally linked to GDP. In the EU and Japan, there is some incipient evidence of decoupling.

Fuel WTW carbon [g CO$_2$/MJ$_{fuel}$]

Vehicle efficiency [MJ$_{fuel}$/veh-km]

CO$_2$ emissions [g CO$_2$]

Freight activity [tonne-km]

Loading factor [veh/tonne]

Maximizing vehicle loading can reduce CO$_2$ emissions, but has clear boundaries.

Vehicle efficiency is the biggest lever to reduce freight’s energy demand

- **Fuel WTW carbon** \([\text{g } \text{CO}_2/\text{MJ}_{\text{fuel}}]\)
- **Vehicle efficiency** \([\text{MJ}_{\text{fuel}}/\text{veh-km}]\)
- **Freight activity** \([\text{tonne-km}]\)
- **Loading factor** \([\text{veh/tonne}]\)

Why regulate HD efficiency?

Market barriers for the market uptake of fuel efficient technologies
How can we improve the fuel efficiency of HDVs?

**Fuel-saving technology areas**

- Telematics, intelligent controls, and driver aids
- Enhanced aerodynamics
- Improved engine
- Idle reduction technology
- Advanced transmission and driveline
- Reduced accessory loads
- Reduced rolling resistance tires and inflation control systems
- Weight reduction with material substitution

Figure 2: Tractor-trailer fuel-saving technology areas

The motivation for saving fuel is clear

In most regions, fuel is the largest (or second largest) expense in the trucking sector.
There is no certified fuel consumption data available. Unofficial data suggests limited efficiency improvements in the past.

4 key barriers delay technology uptake

**Uncertain return on investment**
Will the technologies perform as expected? What will fuel prices be in the future?

**Capital cost constraints**
Can the fleet get access to additional capital?

**Split incentives**
Are the equipment owner and operator different entities with different motivations? Who makes the technology purchase vs. who pays for fuel?

**Lack of technology availability**
Are the technologies available in the market? Available from a preferred supplier?

3 types of policy measures can combat barriers and accelerate technology adoption

**Fuel efficiency standards**
Setting and enforcing mandatory efficiency performance targets for heavy-duty vehicles

**Market-based approaches**
Providing fleets and shippers better information for making decisions around fuel-saving technologies and strategies

**Fiscal measures**
- Taxing fuels and vehicles to encourage the purchase of more fuel-efficient vehicles
- Supporting infrastructure and incentive schemes for advanced technology and alternative fuel vehicles

What are the key elements of HD efficiency programs?
Tractor-trailer CO₂ standards around the world

Missing from this chart:

Europe just announced its proposal for HDV CO₂ standards for the years 2025 and 2030. They aim to reduce CO₂ emissions of the regulated categories in 15% and 30% by 2025 and 2030 respectively, compared to 2019.

### Details of HDV standards developments around the globe

(HDV CO₂ standards for the EU were proposed yesterday)

<table>
<thead>
<tr>
<th>Type</th>
<th>FE &amp; CO₂ (ex. Canada); CAFE</th>
<th>FE; individual vehicle</th>
<th>FE; CAFE</th>
<th>FE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle scope</td>
<td>GVWR &gt; 3.85t 19 sub-categories, by vehicle type / duty cycle and GVW</td>
<td>GVW &gt; 3.5t 66 sub-categories, by vehicle type / duty cycle and GVW</td>
<td>GVW &gt; 3.5t 25 sub-categories, by type (bus/lorry) and GVW</td>
<td>&gt;12t 10 sub-categories, by GVW, axles, and type (rigid or tractor)</td>
</tr>
<tr>
<td>Certification</td>
<td>Component testing and simulation. Separate engine standard.</td>
<td>Chassis dyno (base vehicles) or whole vehicle simulation (variants).</td>
<td>Engine testing (map) and vehicle simulation. Second phase includes aero and tires testing.</td>
<td>Constant speed fuel consumption (CSFC) standards. Track testing at 40/60km/h</td>
</tr>
<tr>
<td>ZEV incentives</td>
<td>Super-credits</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>
Policy options for improving HDV efficiency

**Vehicle fuel efficiency and GHG standards**
- Setting mandatory efficiency performance targets for heavy-duty vehicles
- Ensuring compliance with reporting requirements and selective auditing

**Market-based approaches**
- Providing fleets and shippers better information for making decisions around fuel-saving technologies and strategies
- Measuring and benchmarking fleet performance

**Fiscal measures**
- Taxing fuels and vehicles to encourage the purchase of more fuel-efficient vehicles
- Supporting infrastructure and incentive schemes for advanced technology and alternative fuel vehicles

**CO₂ certification methodology**

Certification methodology  Vehicle simulation
Most regions use HDV simulation in combination with component certification to determine CO₂ emissions.

**Simulation Model**

- **Payload**
  - ~1/2 payload
  - Full Payload

- **Rolling resistance, aerodynamic drag**
  - From Testing
  - Standard Value

- **Chassis dyno testing**
  - (base vehicles tested, variants simulated)

- **Test cycles**
  - 3 cycles (weighted, incl. grade)
  - 2 cycles (weighted, incl. grade)
  - 1 cycle (‘mini-cycles’ weighted)
  - 5 cycles (incl. grade)

- **Engine map**
  - From Testing

- **Transmission and axle losses**
  - From Testing
ICCT White paper: Fuel consumption simulation of HDVs in the EU: Comparisons and limitations (2018)

- A new comparison study of the latest releases of GEM and VECTO
- Although focused on VECTO, it describes the model architectures of both GEM and VECTO
- The results of this new study are the focus of this presentation
- Publication expected in February 2018

US and Canada HDV fuel consumption certification

Standard vehicle specifications

GEM - Engine cycle generation

Engine dyno mapping

Engine testing: Cycle averaged map

Coastdown test

Wind average correction

Transmit correction

Powertrain correction

Declared CO₂ and FC value

Tires test

Transmission and axle test

Off cycle technologies

Powertrain testing option

Input data

Output data

Dyno testing

Correction

Simulation
Europe HDV fuel consumption certification

- Europe HDV fuel consumption certification
- Engine dyno mapping
- WHTC test
- VECTO
- Constant speed air drag test
- Transmission and axle test
- Tires test
- Cross wind and speed profile correction
- Vertical load correction
- Transient correction
- Auxiliaries
- Declared CO₂ and FC value

Input data  Output data  Dyno testing  Correction  Simulation
Comparison results: Constant speed cycles with grade

Absolute error < 2%

Despite the differences in model architecture (forward vs backward-looking), driver model, and shifting strategy; both VECTO and GEM produce similar fuel consumption results.
Both GEM and VECTO can be adapted to account for the differences across regions. VECTO’s engineering mode provides a user friendly interface to modify drive cycles, payloads, and vehicle details. GEM can also be modified accessing the source code, however, this implies more effort.

VECTO and GEM show very good agreement when simulated over a large set of identical vehicles.

The accurate simulation of CO₂ emissions of HDVs is more dependent on the component input data than on the selected model (VECTO vs GEM). Harmonization of component certification benefits the implementation of future regulatory measures.
Certified component performance data

There are five key components that are measured to provide the necessary input for the simulation tools:

- Engine
- Transmission and axle
- Aerodynamic drag
- Tire rolling resistance
- Other vehicle components / characteristics
Regulations for component certification in the EU and the US


The US and EU component certification methodologies have several common points.

- Axles, tires, and engine mapping procedures are similar.
- Key differences include the aerodynamic drag determination methodology and the engine transient correction.

Harmonization of component certification has many advantages:

- Facilitates transparent comparison of performance between different markets.
- Facilitates the implementation of future regulatory measures.
- Facilitates adapting GEM/VECTO to country-specific needs.
- Streamlined processes and reduced cost of compliance for international manufacturers.
Vehicle segmentation

A comparison of China, India, the U.S. and the EU.
Objectives of the market segmentation

- Separate vehicles and components in groups with similar usage and fuel consumption.
- Enable the use of specific duty cycles and CO₂ emissions targets for each segment.
- Identify the vehicle segments with high fuel consumption. The vehicle segment with the highest market share is not necessarily the same as the one with the highest fuel consumption.
- Segmentation of engines and trailers is necessary in the case of separate policy measures addressing these components.
GVW and vehicle type composition for different HDV markets (2014)

Engine displacement distribution for HDVs in four large markets (2014)

Examples of market segmentation

Complete vehicles
US HDV segmentation for GHG regulation

Vocational vehicles (Rigid, classes 2b to 8)

- LHD (Class 2-5)
  - Urban Multipurpose Regional
  - SI CI
- MHD (Class 6-7)
  - Urban Multipurpose Regional
  - SI CI
- HHD (Class 8)
  - Urban Multipurpose Regional

Class 7 and Class 8 tractors

- Class 7, day cab
  - High roof
  - Mid roof
  - Low roof
- Class 8, day cab
  - High roof
  - Mid roof
  - Low roof
- Class 8, sleeper cab
  - High roof
  - Mid roof
  - Low roof
- Heavy haul

Source: https://jalopnik.com/truck-sizes-classification-explained-from-tacomas-to-1613958192
EU HDV segmentation for CO₂ certification

### 4x2

<table>
<thead>
<tr>
<th>Axle type</th>
<th>Chassis configuration</th>
<th>Gross vehicle weight ( tonnes)</th>
<th>Vehicle group</th>
<th>Regulatory cycles* and payloads* used in VECTO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rigid</td>
<td>&gt;5.5 - &lt;7.5</td>
<td>0</td>
<td>Not considered by the regulation</td>
<td></td>
</tr>
<tr>
<td>Rigid (or tractor)</td>
<td>7.5 - 10</td>
<td>1</td>
<td>RD (50%), UD (50%)</td>
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<tr>
<td>Rigid (or tractor)</td>
<td>&gt;10 - 12</td>
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<td>LH (75%), RD (50%), UD (50%)</td>
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<tr>
<td>Rigid (or tractor)</td>
<td>&gt;12 - 16</td>
<td>3</td>
<td>RD (50%), UD (50%)</td>
<td></td>
</tr>
<tr>
<td>Rigid</td>
<td>&gt;16</td>
<td>4</td>
<td>LH (14.01), RD (4.41), MU (4.41)</td>
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<tr>
<td>Tractor</td>
<td>&gt;16</td>
<td>5</td>
<td>LH (19.31), RD (12.91)</td>
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</tbody>
</table>

### 4x4

<table>
<thead>
<tr>
<th>Axle type</th>
<th>Chassis configuration</th>
<th>Gross vehicle weight ( tonnes)</th>
<th>Vehicle group</th>
<th>Regulatory cycles* and payloads* used in VECTO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rigid</td>
<td>7.5 - 16</td>
<td>6</td>
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</tr>
<tr>
<td>Rigid</td>
<td>&gt;16</td>
<td>7</td>
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<tr>
<td>Tractor</td>
<td>&gt;16</td>
<td>8</td>
<td>Not considered by the regulation</td>
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</tbody>
</table>

### 6x2

<table>
<thead>
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<th>Axle type</th>
<th>Chassis configuration</th>
<th>Gross vehicle weight ( tonnes)</th>
<th>Vehicle group</th>
<th>Regulatory cycles* and payloads* used in VECTO</th>
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</thead>
<tbody>
<tr>
<td>Rigid</td>
<td>all weights</td>
<td>9</td>
<td>LH (19.31), RD (7.11), MU (7.11)</td>
<td></td>
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<tr>
<td>Tractor</td>
<td>all weights</td>
<td>10</td>
<td>LH (19.31), RD (12.91)</td>
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### 6x4

<table>
<thead>
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<th>Axle type</th>
<th>Chassis configuration</th>
<th>Gross vehicle weight ( tonnes)</th>
<th>Vehicle group</th>
<th>Regulatory cycles* and payloads* used in VECTO</th>
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</thead>
<tbody>
<tr>
<td>Rigid</td>
<td>all weights</td>
<td>11</td>
<td>LH (19.31), RD (7.11), MU (7.11), C(7.11)</td>
<td></td>
</tr>
<tr>
<td>Tractor</td>
<td>all weights</td>
<td>12</td>
<td>LH (19.31), RD (12.91), C (12.91)</td>
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</tbody>
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### 6x6

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<th>Axle type</th>
<th>Chassis configuration</th>
<th>Gross vehicle weight ( tonnes)</th>
<th>Vehicle group</th>
<th>Regulatory cycles* and payloads* used in VECTO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rigid</td>
<td>all weights</td>
<td>13</td>
<td>Not considered by the regulation</td>
<td></td>
</tr>
<tr>
<td>Tractor</td>
<td>all weights</td>
<td>14</td>
<td>Not considered by the regulation</td>
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</table>

### 8x2

<table>
<thead>
<tr>
<th>Axle type</th>
<th>Chassis configuration</th>
<th>Gross vehicle weight ( tonnes)</th>
<th>Vehicle group</th>
<th>Regulatory cycles* and payloads* used in VECTO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rigid</td>
<td>all weights</td>
<td>15</td>
<td>Not considered by the regulation</td>
<td></td>
</tr>
</tbody>
</table>

### 8x4

<table>
<thead>
<tr>
<th>Axle type</th>
<th>Chassis configuration</th>
<th>Gross vehicle weight ( tonnes)</th>
<th>Vehicle group</th>
<th>Regulatory cycles* and payloads* used in VECTO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rigid</td>
<td>all weights</td>
<td>16</td>
<td>C (7.11)</td>
<td></td>
</tr>
</tbody>
</table>

### 8x6 8x8

<table>
<thead>
<tr>
<th>Axle type</th>
<th>Chassis configuration</th>
<th>Gross vehicle weight ( tonnes)</th>
<th>Vehicle group</th>
<th>Regulatory cycles* and payloads* used in VECTO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rigid</td>
<td>all weights</td>
<td>17</td>
<td>Not considered by the regulation</td>
<td></td>
</tr>
</tbody>
</table>

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**Possible further sub-division of the vehicle groups under development for setting mandatory CO₂ targets.**

**Possibilities: Group sub-division based on engine power, or/and cabin type (day or sleeper).**

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a. Long haul (LH), Regional delivery (RD), Urban delivery (UD), Municipal Utility (MU), Construction (C). Rigid trucks include long haul cycle use an additional trailer.

b. Number in brackets is the payload in tonnes. For vehicle groups 1, 2, and 3, the payload is determined on the basis of the percentage number in brackets, which represents the approximate fraction of the maximum payload that is used for the test cycle.

d. New vehicles belonging to groups 4, 5, 9, and 10 will be certified from January 1, 2019. Vehicle registrations belonging to groups 4, 5, 9, and 10 will be certified from July 1, 2019.

e. Vehicle registrations belonging to groups 1, 2, and 3 must be certified from January 1, 2020.

f. Vehicle registrations belonging to groups 11, 12, and 16, must be certified from July 1, 2020.

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China HDV segmentation for CO₂ standards

- Specialized Delivery: 27.6%
- Tractor: 20.3%
- Dump Truck: 18.7%
- Truck: 7.4%
- Coach: 6.0%
- City Bus: 4.7%
- Specialized Vocational (Not regulated): 4.6%
- Alternative Fuel HDV (Not regulated): 10.8%

# India and Japan’s HDV segmentation for fuel consumption standards

<table>
<thead>
<tr>
<th>Rigid truck</th>
<th>GVW Bin (tonnes)</th>
<th>Axle Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.0-16.2</td>
<td>4x2</td>
<td></td>
</tr>
<tr>
<td>16.2-25.0</td>
<td>6x2</td>
<td></td>
</tr>
<tr>
<td>16.2-25.0</td>
<td>6x2</td>
<td></td>
</tr>
<tr>
<td>25.0-31.0</td>
<td>8x4</td>
<td></td>
</tr>
<tr>
<td>25.0-31.0</td>
<td>8x4</td>
<td></td>
</tr>
<tr>
<td>31.0-37.0</td>
<td>10x2</td>
<td></td>
</tr>
<tr>
<td>Tractor-trailer</td>
<td>35.2-40.2</td>
<td>4x2</td>
</tr>
<tr>
<td>40.2-49.0</td>
<td>6x2</td>
<td></td>
</tr>
<tr>
<td>40.2-49.0</td>
<td>6x4</td>
<td></td>
</tr>
</tbody>
</table>

| Bus | 12.0 and above | All Configuration |

<table>
<thead>
<tr>
<th>Rigid freight trucks:</th>
<th>PL ≤ 1.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.5 &lt; PL ≤ 2</td>
</tr>
<tr>
<td>2</td>
<td>2 &lt; PL ≤ 3</td>
</tr>
<tr>
<td>3</td>
<td>3 &lt; PL</td>
</tr>
<tr>
<td>4</td>
<td>3.5 &lt; GVW ≤ 7.5</td>
</tr>
<tr>
<td>5</td>
<td>7.5 &lt; GVW ≤ 8</td>
</tr>
<tr>
<td>6</td>
<td>8 &lt; GVW ≤ 10</td>
</tr>
<tr>
<td>7</td>
<td>10 &lt; GVW ≤ 12</td>
</tr>
<tr>
<td>8</td>
<td>12 &lt; GVW ≤ 14</td>
</tr>
<tr>
<td>9</td>
<td>14 &lt; GVW ≤ 16</td>
</tr>
<tr>
<td>10</td>
<td>16 &lt; GVW ≤ 20</td>
</tr>
<tr>
<td>11</td>
<td>20 &lt; GVW</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tractor trucks:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
</tbody>
</table>


Vehicle segmentation– Summary

- The market segmentation and definition of duty cycles are country specific exercises. However, experiences and concepts applied in other regions can be adapted.

- There is no perfect segmentation. A balance between complexity and representativeness is necessary.

- The market segmentation divides the vehicle fleet into different segments with similar application and fuel consumption. Typical differentiators are vehicle weight, chassis configuration, and axle configuration.

- Further segmentation can be achieved by cabin type, engine power, intended vehicle use, among others.
Questions? Contact the HDV team at the ICCT

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