Market segmentation and duty cycles

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G20 Transport Task Group:

Deep Dive to Support Heavy-Duty Vehicle Efficiency Labeling and Standards Meeting #4

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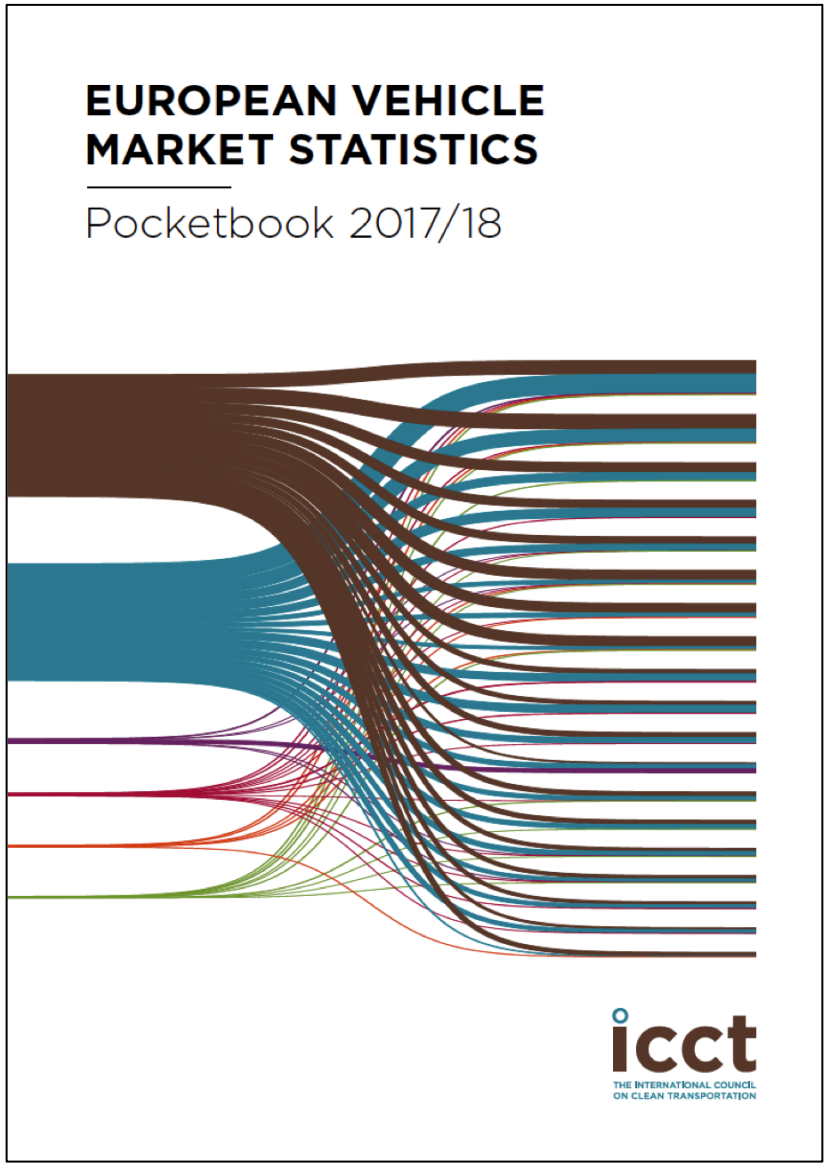
Introduction

- Vehicle simulation and component certification procedures can be easily adapted to the other regions.
- On the other hand, the definition of the heavy-duty vehicle segments and duty cycles are market-specific.
- This presentation aims at providing examples from different regions, and the solutions adopted for addressing the variety of heavy-duty vehicle types and uses.

ICCT market studies for HDVs

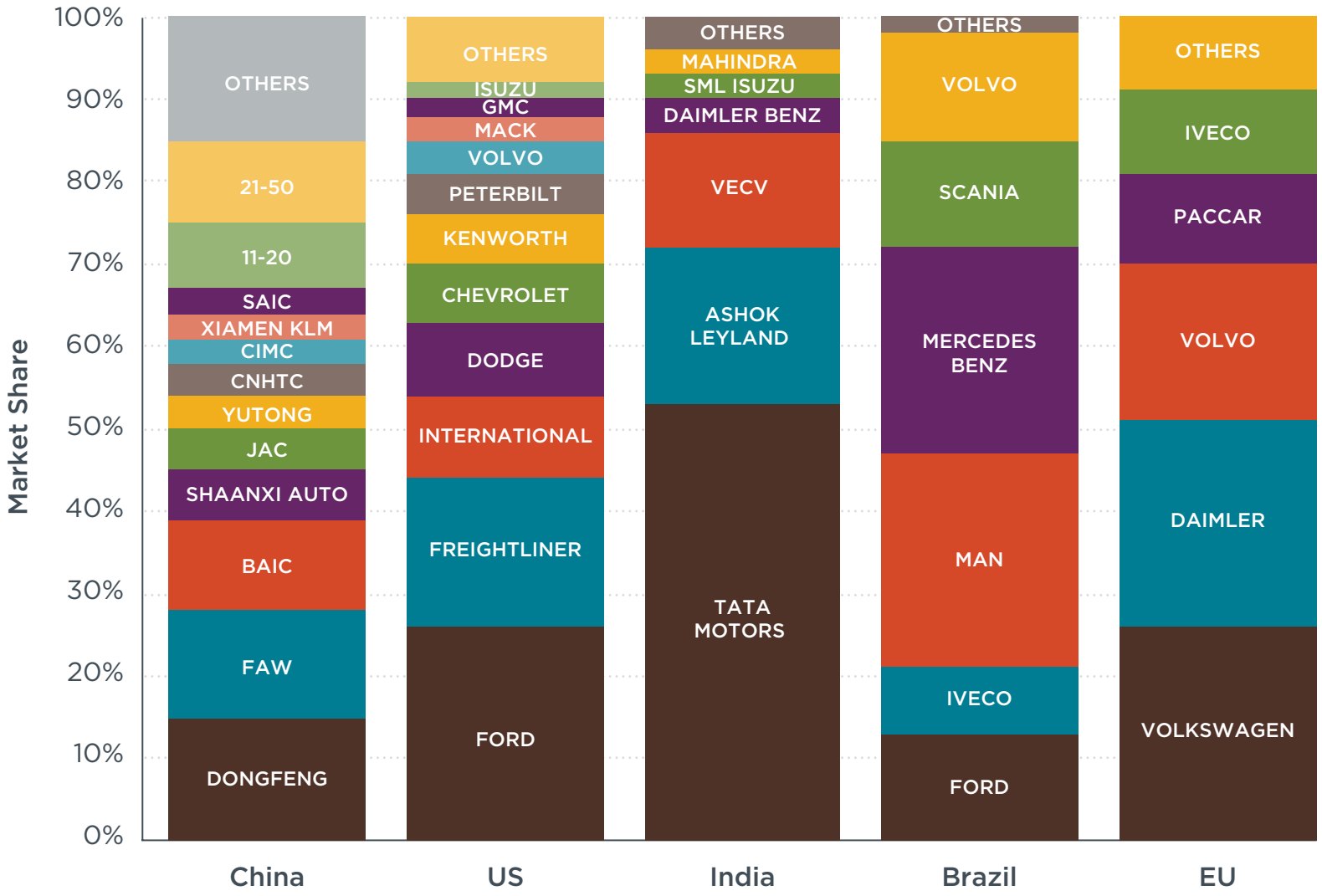


- European vehicle market statistics, 2017/2018
  https://www.theicct.org/publications/european-vehicle-market-statistics-20172018
- Market analysis and fuel efficiency technology potential of heavy-duty vehicles in China
  https://www.theicct.org/publications/HDV-china-mkt-analysis-and-fuel-efficiency-tech-potential
- Market Penetration of Fuel Efficiency Technologies for Heavy-Duty Vehicles in the EU, US and China
  http://www.theicct.org/market-penetration-HDV-fuel-efficiency-technologies
- Market analysis of heavy-duty commercial trailers in Canada
  http://www.theicct.org/market-analysis-heavy-duty-commercial-trailers-canada
- Overview of the heavy-duty vehicle market and CO2 emissions in the European Union
  http://www.theicct.org/overview-heavy-duty-vehicle-market-and-co2-emissions-european-union
- Market analysis of heavy-duty vehicles in India
  https://www.theicct.org/publications/market-analysis-heavy-duty-vehicles-india

Key differences between the major markets

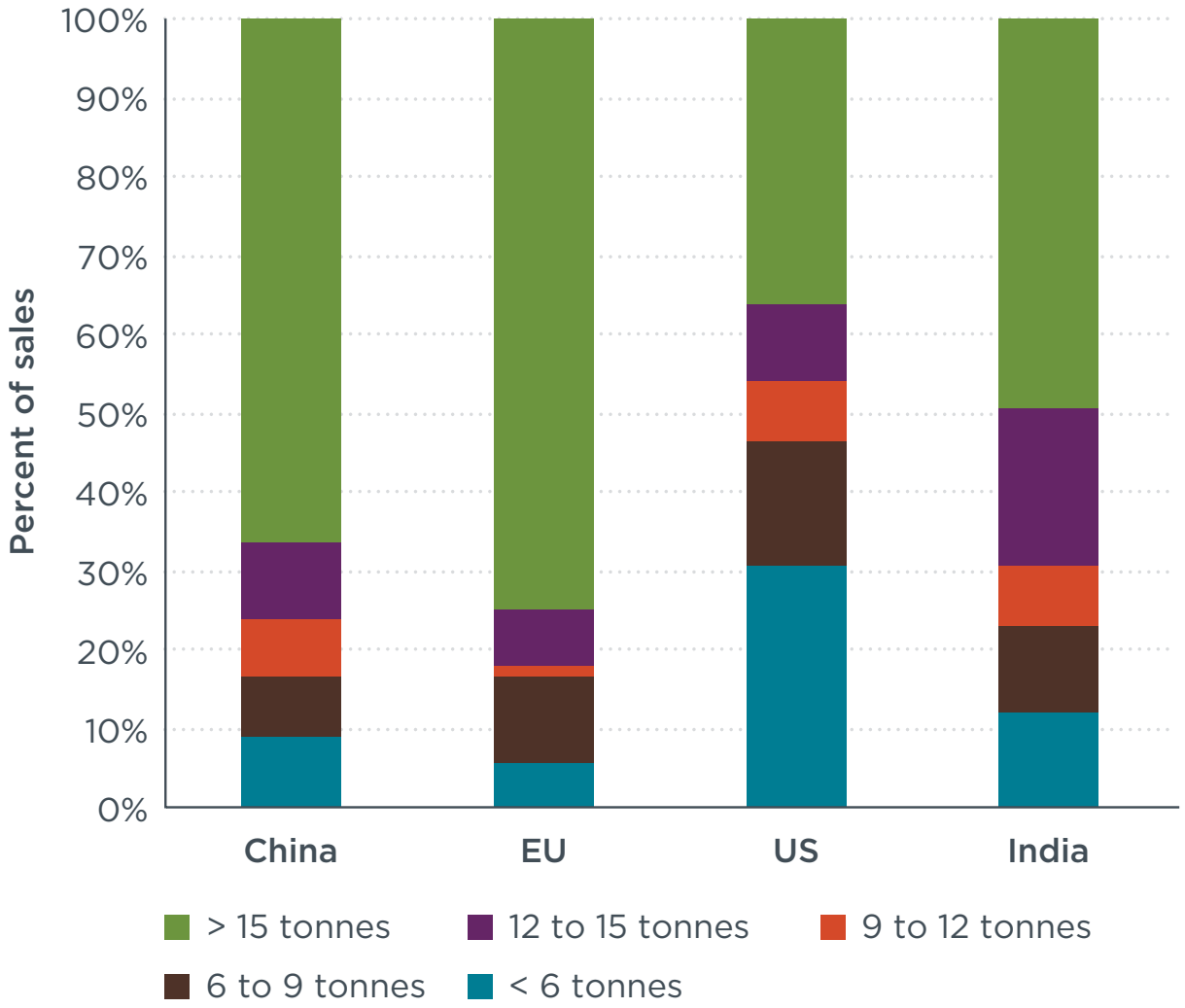
A comparison of China, India, the U.S. and the EU.

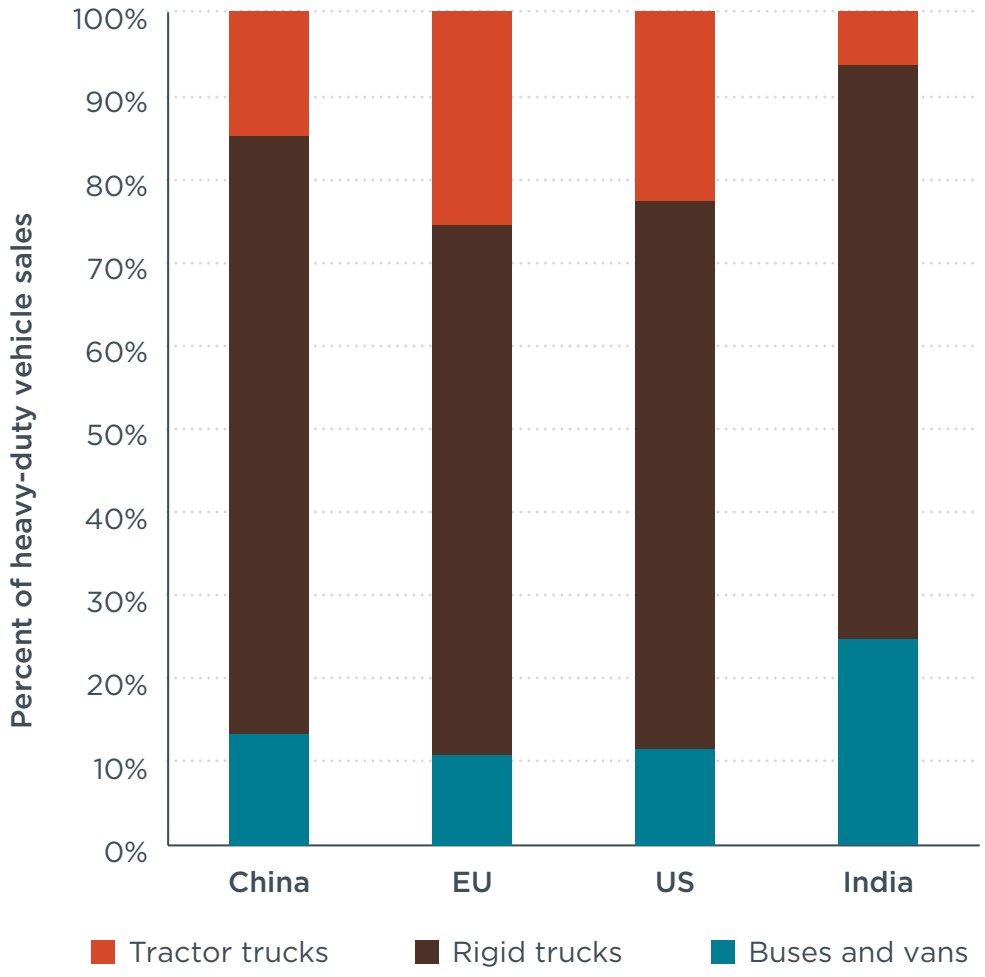
The market consolidation differs significantly between regions (2016)



Delgado, O., & Li, H. (2017). *Market analysis and fuel efficiency technology potential of heavy-duty vehicles in China*. The International Council on Clean Transportation. www.theicct.org/publications/HDV-china-mkt-analysis-and-fuel-efficiency-tech-potential

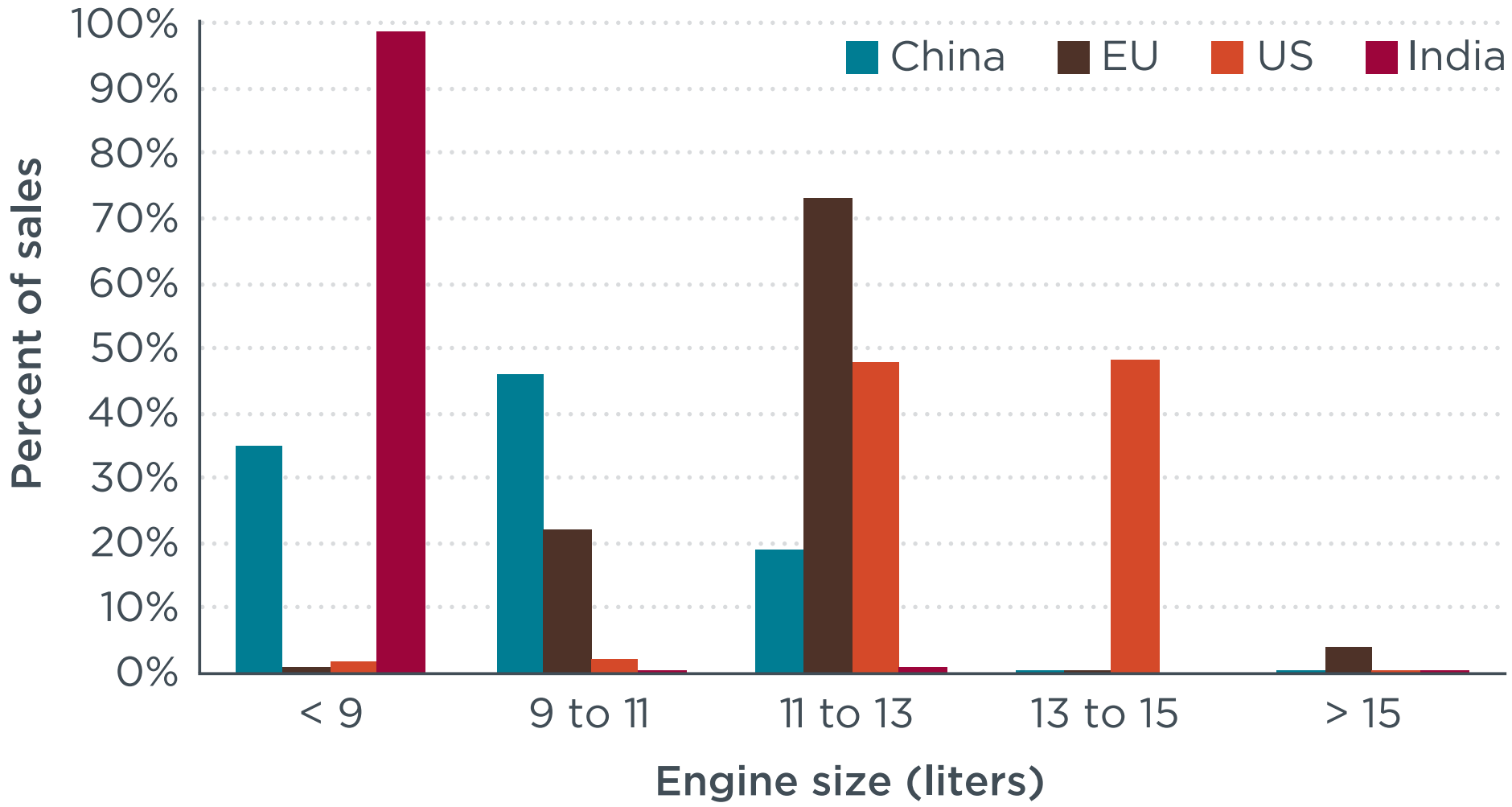
GVW and vehicle type composition for different HDV markets (2014)





Sharpe, B. (2015). *Market analysis of heavy-duty vehicles in India*. International Council on Clean Transportation. https://www.theicct.org/publications/market-analysis-heavy-duty-vehicles-india

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



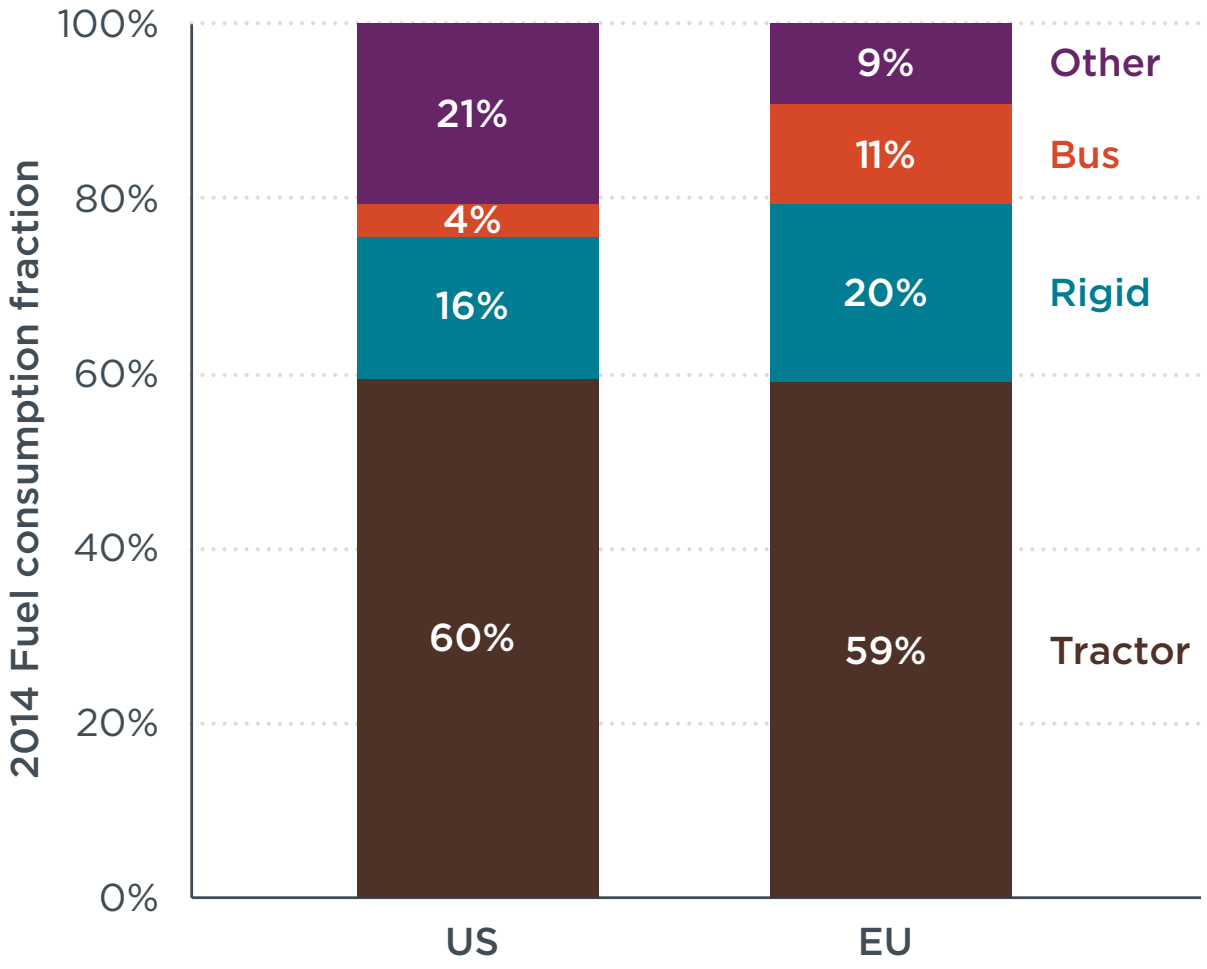
Sharpe, B. (2015). *Market analysis of heavy-duty vehicles in India*. International Council on Clean Transportation. https://www.theicct.org/publications/market-analysis-heavy-duty-vehicles-india

Examples of market segmentation

Complete vehicles

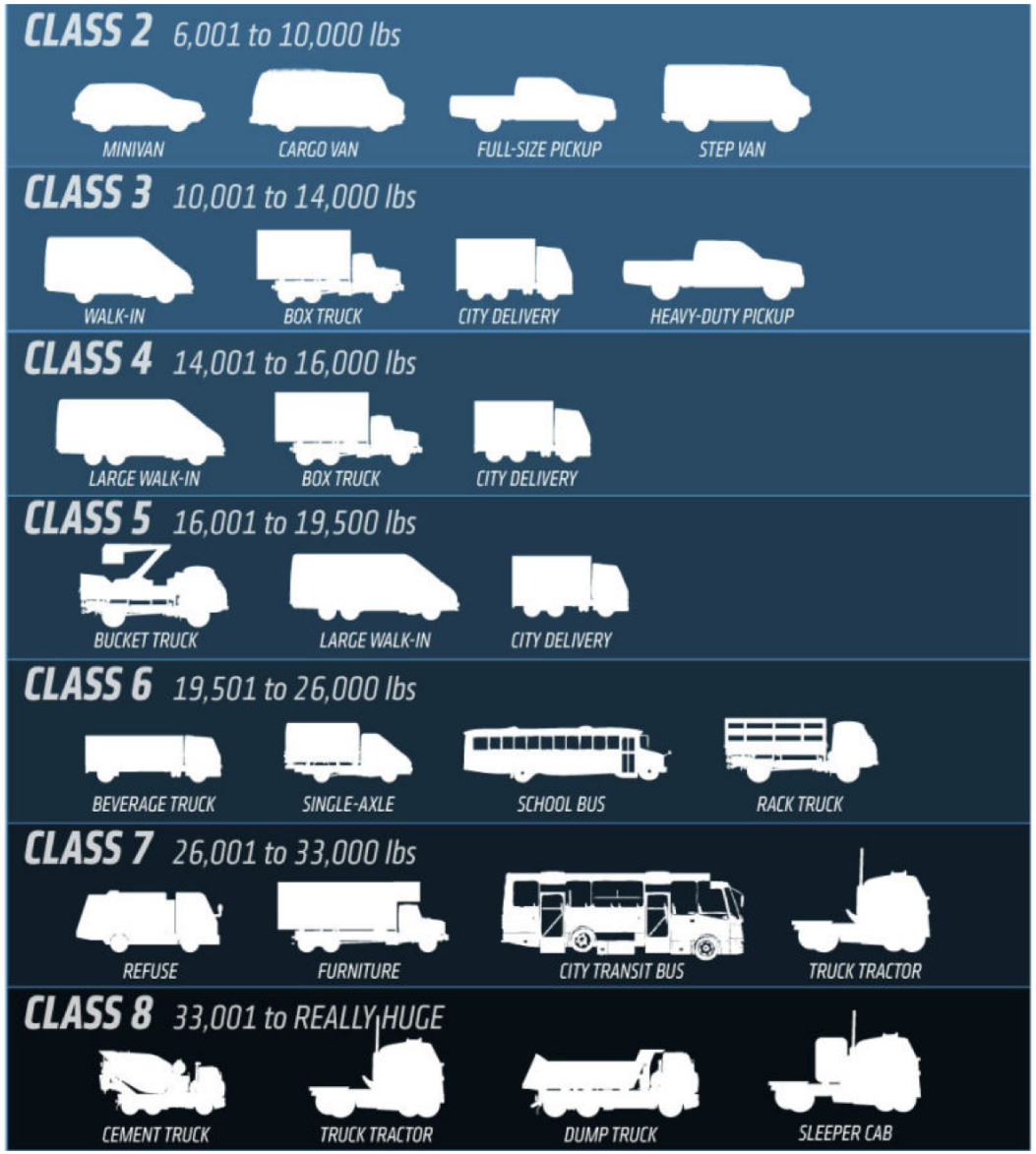
Objectives of the market segmentation

- Separate vehicles and components in groups with similar usage and fuel consumption.
- Enable the use of specific duty cycles and CO_2 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 this components.



Muncrief, R., & Sharpe, B. (2015). *Overview of the heavy-duty vehicle market and CO2 emissions in the European Union*. International Council on Clean Transportation. www.theicct.org/overview-heavy-duty-vehicle-market-and-co2-emissions-european-union

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 CO_2 certification

Axle type	Chassis configuration	Gross vehicle weight (tonnes)	Vehicle group	Regulatory cycles[a] and payloads[b] used in VECTO
4x2	Rigid	>3.5 – <7.5	0	Not considered by the regulation
	Rigid (or tractor)	7.5 – 10	1	RD (50%), UD (50%)
	Rigid (or tractor)	>10 – 12	2	LH (75%), RD (50%), UD (50%)
	Rigid (or tractor)	>12 – 16	3	RD (50%), UD (50%)
	Rigid	>16	4	LH (14.0t), RD (4.4t), MU (4.4t)
	Tractor	>16	5	LH (19.3t), RD (12.9t)
4x4	Rigid	7.5 – 16	6	Not considered by the regulation
	Rigid	>16	7	Not considered by the regulation
	Tractor	>16	8	Not considered by the regulation
6x2	Rigid	all weights	9	LH (19.3t), RD (7.1t), MU (7.1t)
	Tractor	all weights	10	LH (19.3t), RD (12.9t)
6x4	Rigid	all weights	11	LH (19.3t), RD (7.1t), MU (7.1t), C(7.1t)
	Tractor	all weights	12	LH (19.3t), RD (12.9t), C (12.9t)
6x6	Rigid	all weights	13	Not considered by the regulation
	Tractor	all weights	14	Not considered by the regulation
8x2	Rigid	all weights	15	Not considered by the regulation
8x4	Rigid	all weights	16	C (7.1t)
8x6 8x8	Rigid	all weights	17	Not considered by the regulation
	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			
	Vehicle registrations belonging to groups 1, 2, and 3 must be certified from January 1, 2020.			
	Vehicle registrations belonging to groups 11, 12, and 16, must be certified from July 1, 2020.			

N2

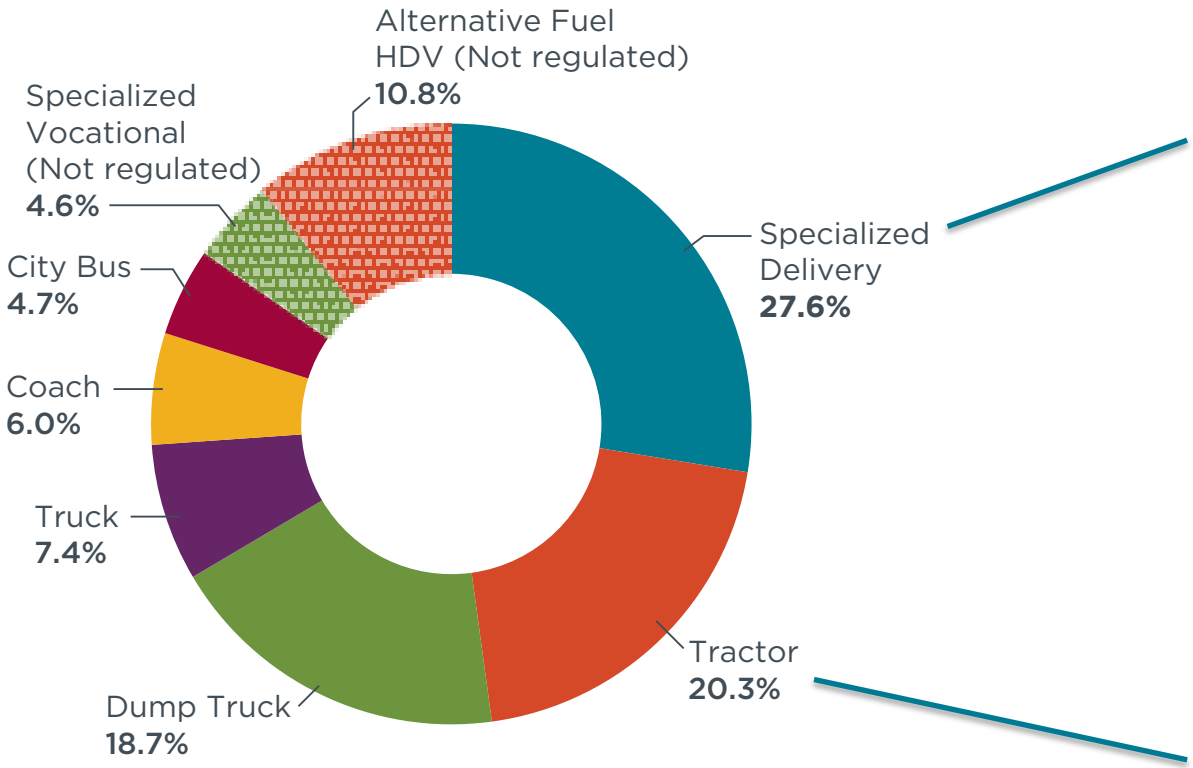
N3

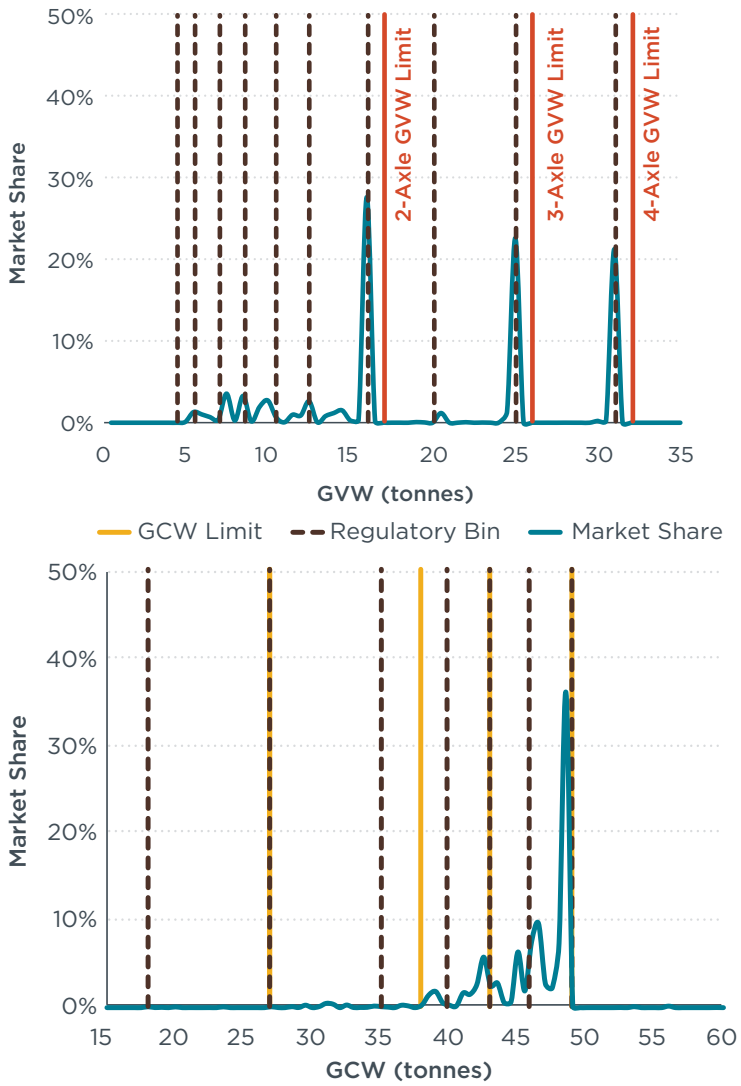
a. Long-Haul (LH), Regional Delivery (RD), Urban Delivery (UD), Municipal Utility (MU), Construction (C). Rigid trucks in the long haul cycle use an additional trailer.
b. Number in brackets is the payload in tonnes. For vehicle groups 1,2, and 3, the payload is dependent on the GVW; the percentage number in brackets refers the approximate fraction of the maximum payload that is used in the vehicle simulation.

- Possible further sub-division of the vehicle groups under development for setting mandatory CO_2 targets.
- Possibilities: Group sub-division based on engine power, or/and cabin type (day or sleeper).

Rodríguez, F. (2018). *Certification of CO2 emissions and fuel consumption of on-road heavy-duty vehicles in the European Union* (Policy update). International Council on Clean Transportation. https://www.theicct.org/publications/certification-co2-emissions-and-fuel-consumption-road-heavy-duty-vehicles-european

China HDV segmentation for CO_2 standards



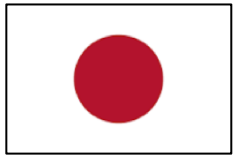


icct THE INTERNATIONAL COUNCIL ON Clean Transportation Delgado, O., & Li, H. (2017). *Market analysis and fuel efficiency technology potential of heavy-duty vehicles in China*. The International Council on Clean Transportation. www.theicct.org/publications/HDV-china-mkt-analysis-and-fuel-efficiency-tech-potential

India and Japan's HDV segmentation for fuel consumption standards

	GVW Bin (tonnes)	Axle Configuration
Rigid truck	12.0-16.2	4x2
	16.2-25.0	6x2
	16.2-25.0	6x4
	25.0-31.0	8x2
	25.0-31.0	8x4
	31.0-37.0	10x2
Tractor-trailer	35.2-40.2	4x2
	40.2-49.0	6x2
	40.2-49.0	6x4
Bus	12.0 and above	All Configuration

Garg, M., & Sharpe, B. (2017). *Fuel consumption standards for heavy-duty vehicles in India*. The International Council on Clean Transportation. www.theicct.org/publications/fuel-consumption-stds-hdvs-india-update-201712



Rigid freight trucks:

1	3.5＜GVW≦7.5	PL≦1.5
2		1.5＜PL≦2
3		2＜PL≦3
4		3＜PL
5	7.5＜GVW≦8	
6	8＜GVW≦10	
7	10＜GVW≦12	
8	12＜GVW≦14	
9	14＜GVW≦16	
10	16＜GVW≦20	
11	20＜GVW	

Tractor trucks:

1	GVW≦20
2	20＜GVW

Ministry of Land, Infrastructure, Transport and Tourism (2017). http://www.mlit.go.jp/report/press/jidosha10_hh_000190.html

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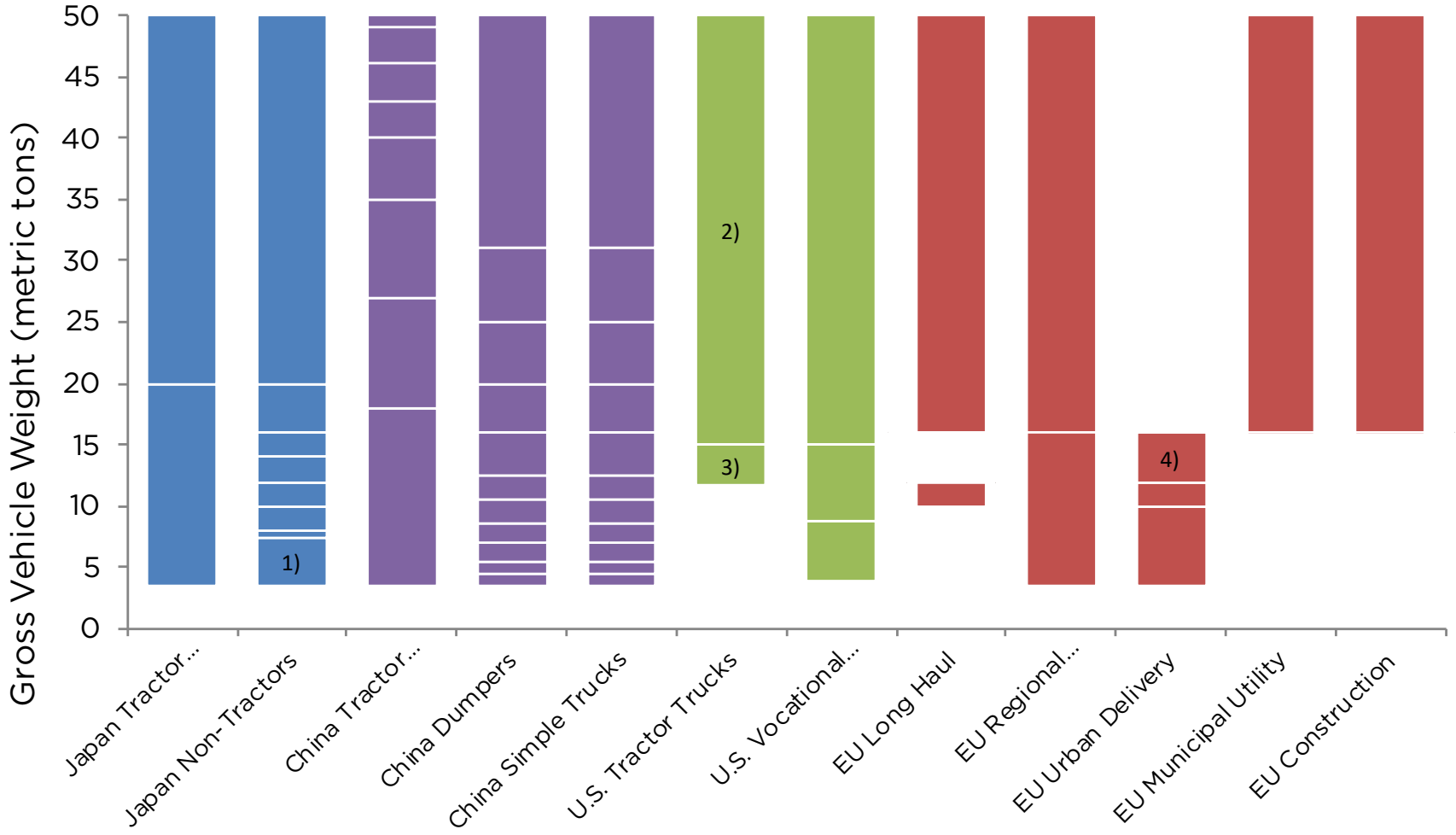
Summary: Segmentation comparison by GVW

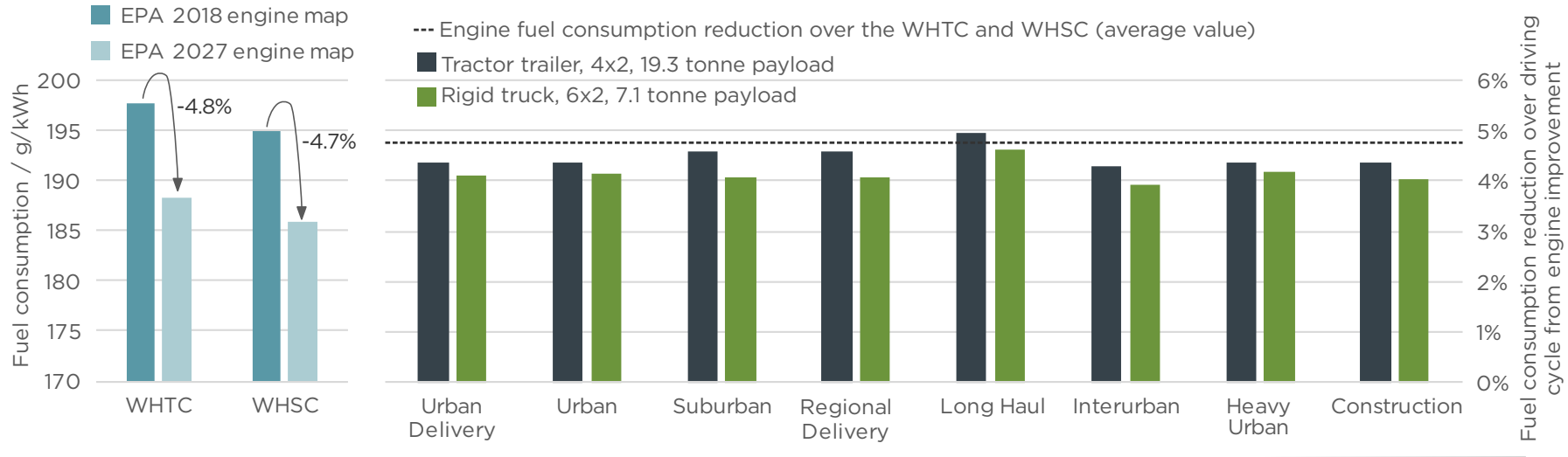


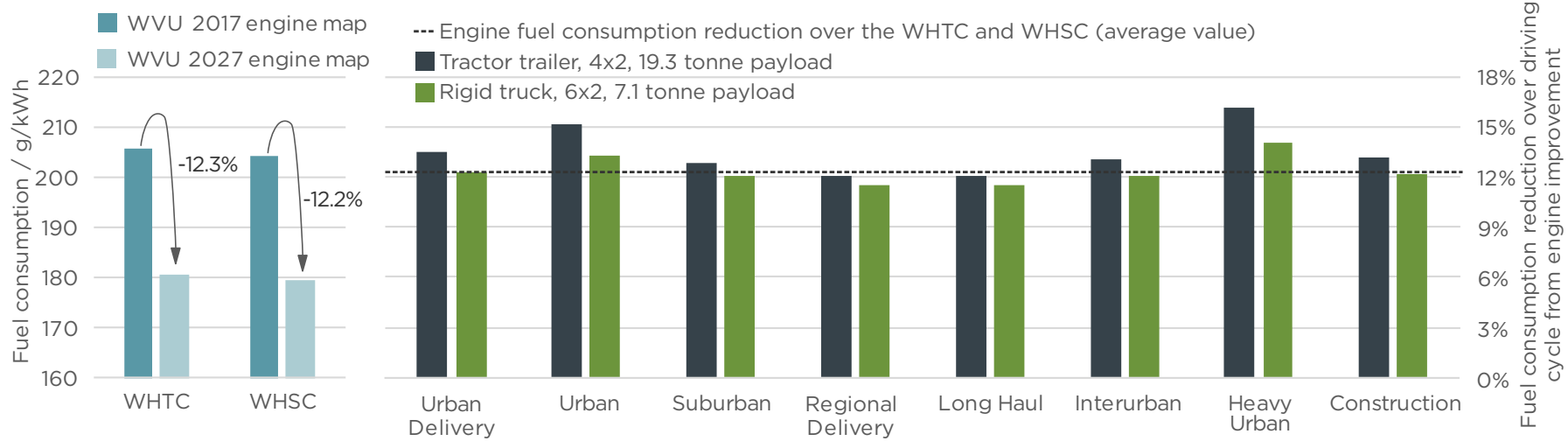
[1] Further divided into four subsegments by maximum payload, [2] Further divided into six subsegments by roof height and cab type, [3] Further divided into three subsegments by roof height, [4] Each EU segment further divided into two to seven subsegments by axle, chassis, and body configuration and weight

Examples of market segmentation

Engines

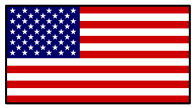
Improvements in engine efficiency translate directly into vehicle efficiency improvements





Muncrief, R., & Rodríguez, F. (2017). *A roadmap for heavy-duty engine CO2 standards within the European Union framework*. The International Council on Clean Transportation. www.theicct.org/publications/roadmap-heavy-duty-engine-co2-standards-within-european-union-framework

Engine segmentation in the US for engine GHG standards



- HD engines in the US are segmented based on the type – tractor or non-tractor – and “primary intended service class” of the vehicle in which the engine will be used.
- For diesel engines, “the primary intended service classes” are light heavy-duty (LHD), medium heavy-duty (MHD), and heavy heavy-duty (HHD).
- The U.S. standard considers that tractor engines are more likely to be driven on the highway in a steady state and that non-tractors are more likely to be driven in transient operation. Therefore, the tractor engines are required to meet a CO_2 limit over a steady-state engine cycle.

Vehicle Type for engine segmentation	GVW (tonnes)
Tractor	11.8 to 15
	15+
Non-tractor	3.9 to 8.8
	8.8 to 15
	15+

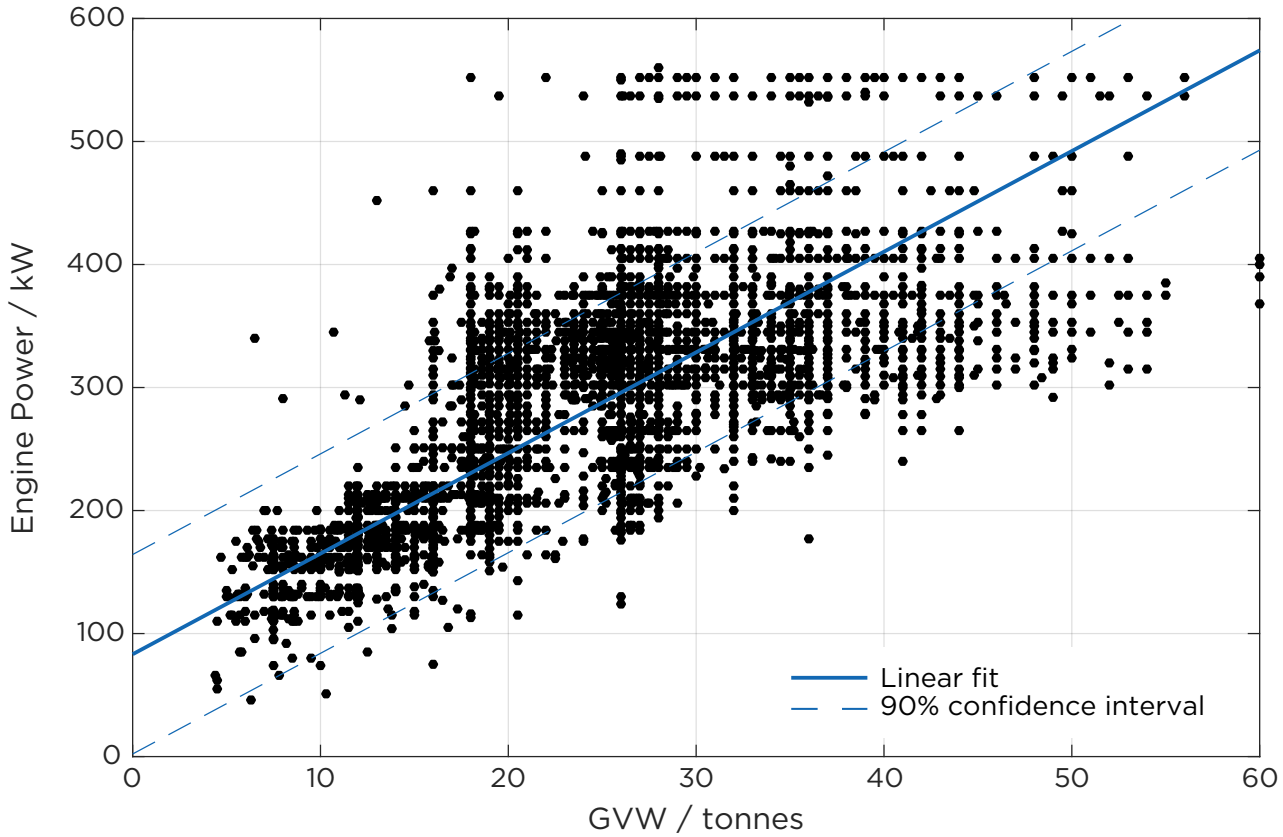
Muncrief, R., & Rodríguez, F. (2017). *A roadmap for heavy-duty engine CO2 standards within the European Union framework*. The International Council on Clean Transportation. www.theicct.org/publications/roadmap-heavy-duty-engine-co2-standards-within-european-union-framework

Alternatives for HD engine segmentation

Grouping by	Advantages	Disadvantages
Vehicle GVWR and type	• Most attractive method for ensuring engines installed in similar types of vehicles are grouped in the same category • Unique engine cycles can be utilized to better reflect real-world operations	Could lead to wide ranges of engine size and power ratings in the same regulatory category → inherent efficiency advantage of large engines could incentivize trend towards bigger engines
Engine size	Parameter is very difficult to change without major hardware overalls → virtual eliminates opportunities for gaming	Very little opportunity to choose different test cycles to more closely match in-use operations
Engine power	Parameter directly corresponds to the grams per brake horsepower metric for evaluating engines	Same as above

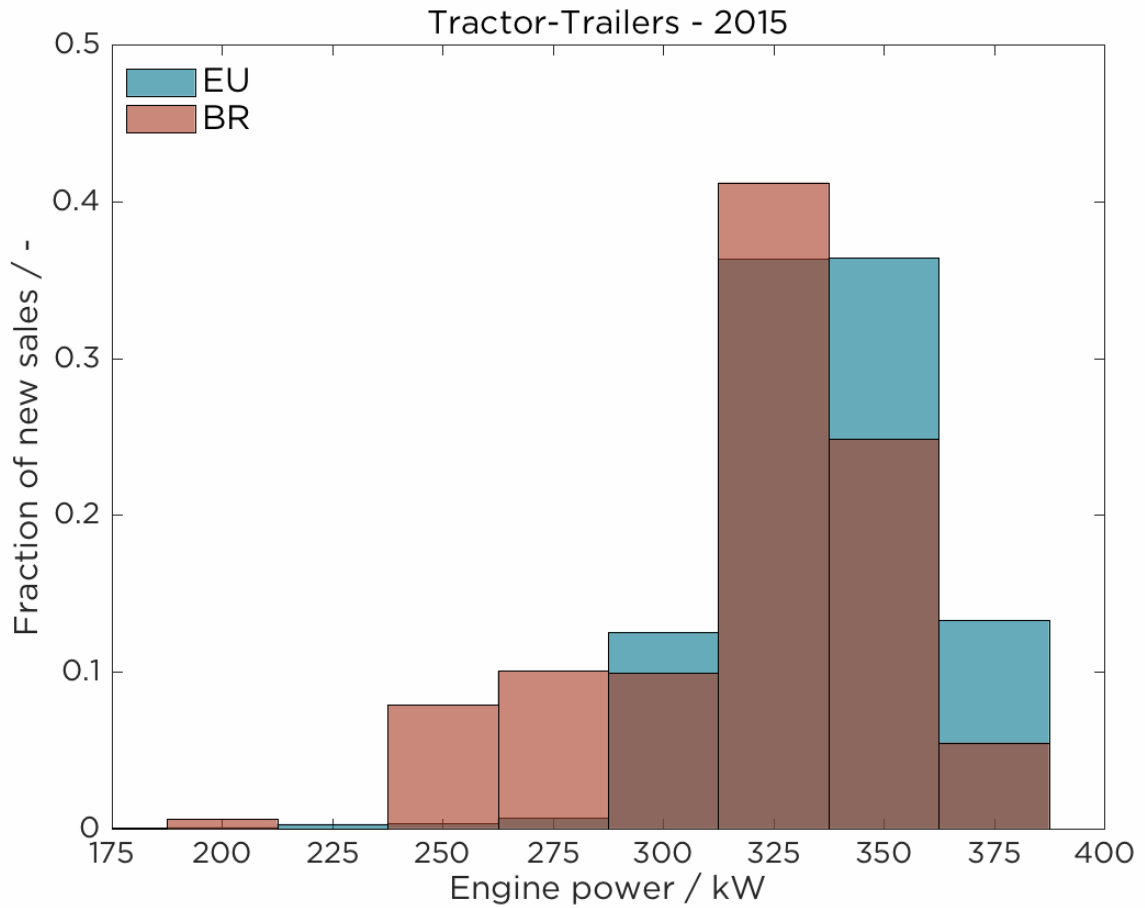
Sharpe, B. (2015). *Market analysis of heavy-duty vehicles in India*. International Council on Clean Transportation. www.theicct.org/publications/market-analysis-heavy-duty-vehicles-india

Correlation between engine power and GVW for non-tractor truck sales in the EU in 2016



Muncrief, R., & Rodríguez, F. (2017). *A roadmap for heavy-duty engine CO2 standards within the European Union framework*. The International Council on Clean Transportation. www.theicct.org/publications/roadmap-heavy-duty-engine-co2-standards-within-european-union-framework

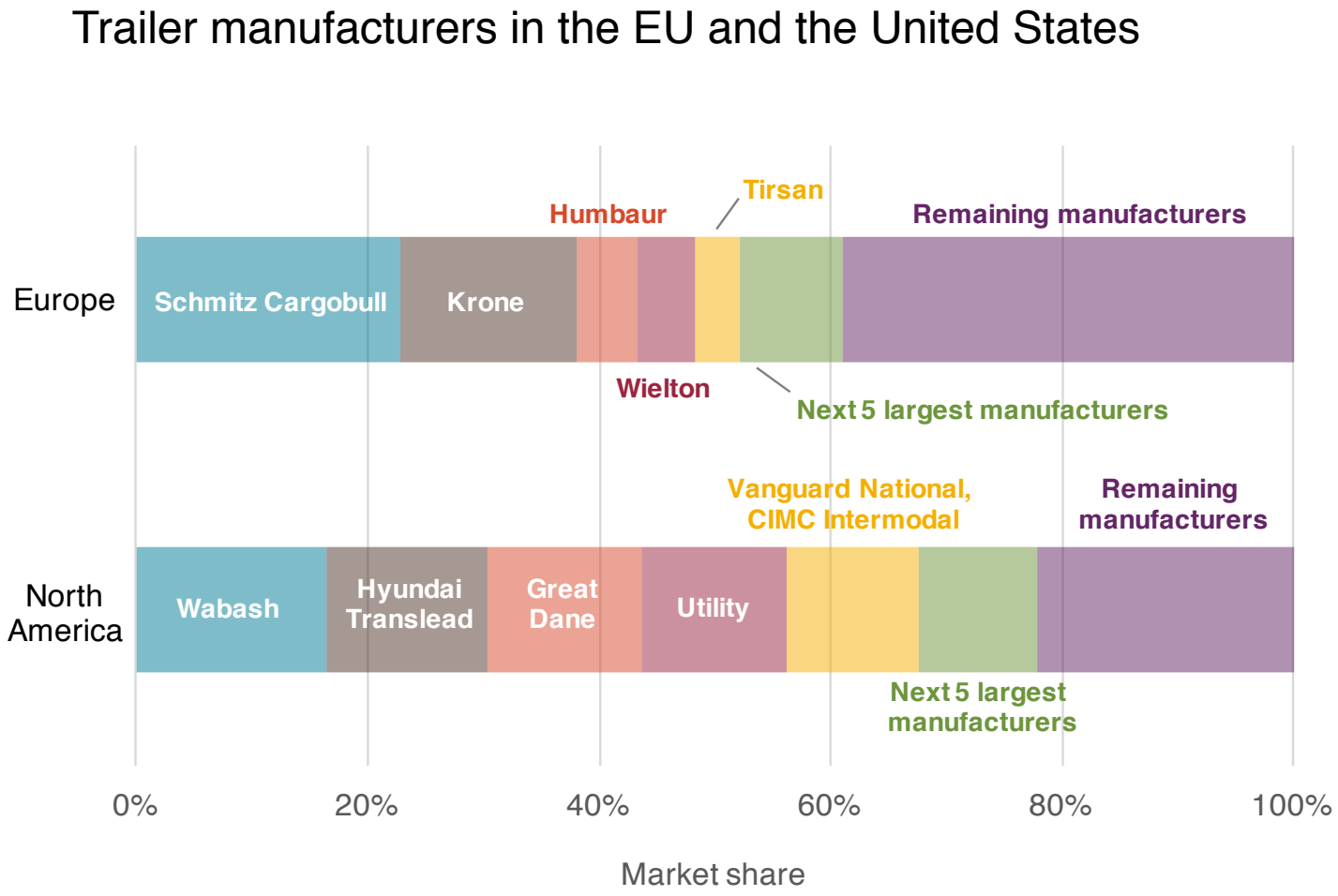
Market dynamics present a challenge for using engine power or displacement for engine segmentation



Examples of market segmentation

Trailers

Trailers have a large technology potential to reduce CO_2 emissions from HDVs. Trailer manufacturers are usually local players.



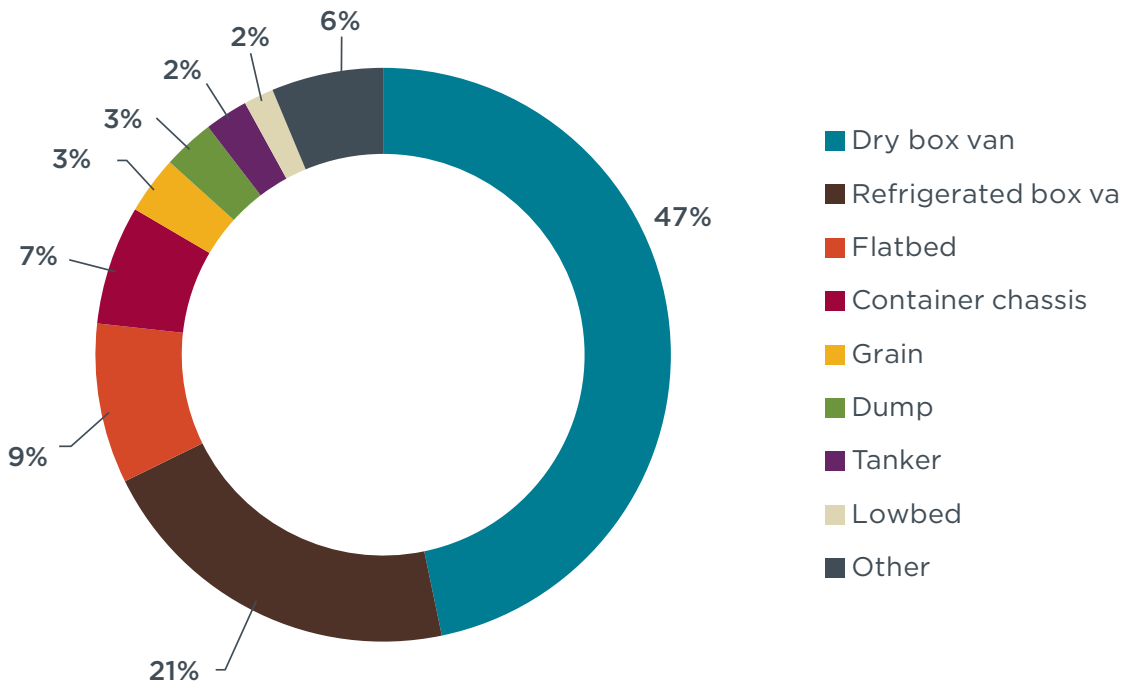
Sharpe, B. (2018). *Market analysis of heavy-duty commercial trailers in Europe* (Publication pending). The International Council on Clean Transportation.

US trailer segmentation for Phase 2 GHG standards

US trailer segmentation

Long box trailers	DRY VAN
	REFRIGERATED VAN
Short box trailers	DRY VAN
	REFRIGERATED VAN
Non-aero box trailers	
Non-box trailers	

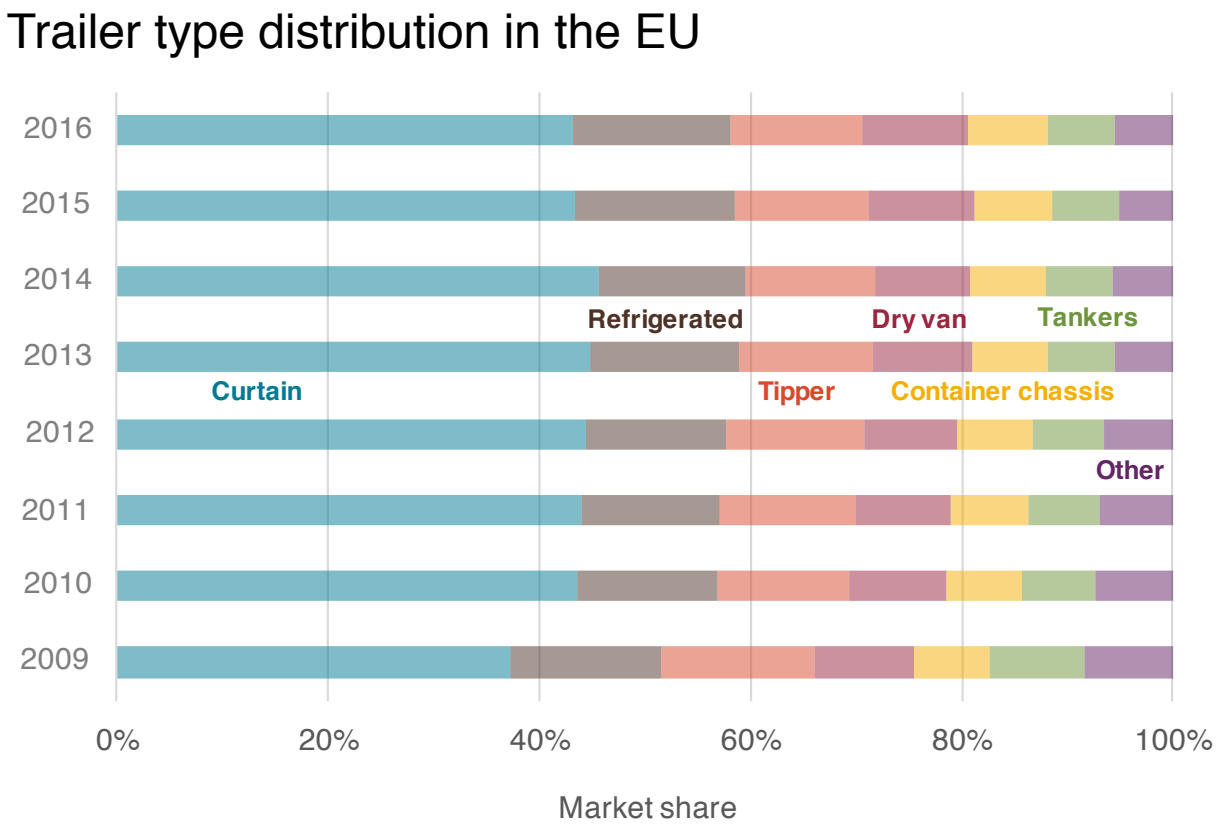
US trailer market distribution between 2003 and 2011

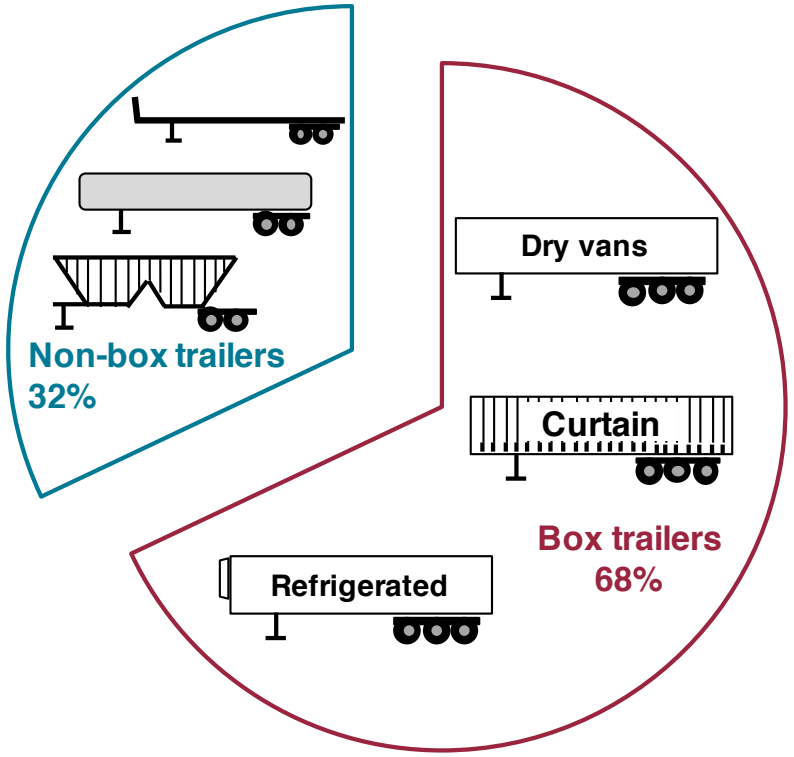


Sharpe, B., Lutsey, N., Delgado, O., & Muncrief, R. (2016). *United States efficiency and greenhouse gas emission regulations for model year 2018-2027 heavy-duty vehicles, engines, and trailers*. International Council on Clean Transportation. www.theicct.org/US-phase2-HDV-efficiency-GHG-regulations-FRM

Sharpe, B. (2016). *Market analysis of heavy-duty commercial trailers in Canada*. International Council on Clean Transportation. www.theicct.org/market-analysis-heavy-duty-commercial-trailers-canada

The EU has a similar trailer distribution as the US, and a similar market segmentation is possible





Sharpe, B. (2018). *Market analysis of heavy-duty commercial trailers in Europe* (Publication pending). The International Council on Clean Transportation.

Duty cycles

Vehicle

The duty cycles should represent real on-road HDV operation

- The definition of representative duty cycles for HDVs is challenging due to the variety of applications.

- The main objective is of the duty cycle design is to give realistic fuel consumption values for all vehicle variants. The definition of the duty cycles is dependent on, among others: vehicle fleet technical specifications, road type (urban, regional, highway), speed limits, topography, traffic conditions, etc.

- Duty cycles can be categorized in two main categories: **Actual speed vs time based** and **target speed vs. distance**

Time-based: World Harmonized Vehicle Cycle (WHVC) 1/2

- The WHVC was developed under the United Nations Economic Commission for Europe (UNECE) World Forum for Harmonization of Vehicle Regulations (WP.29).

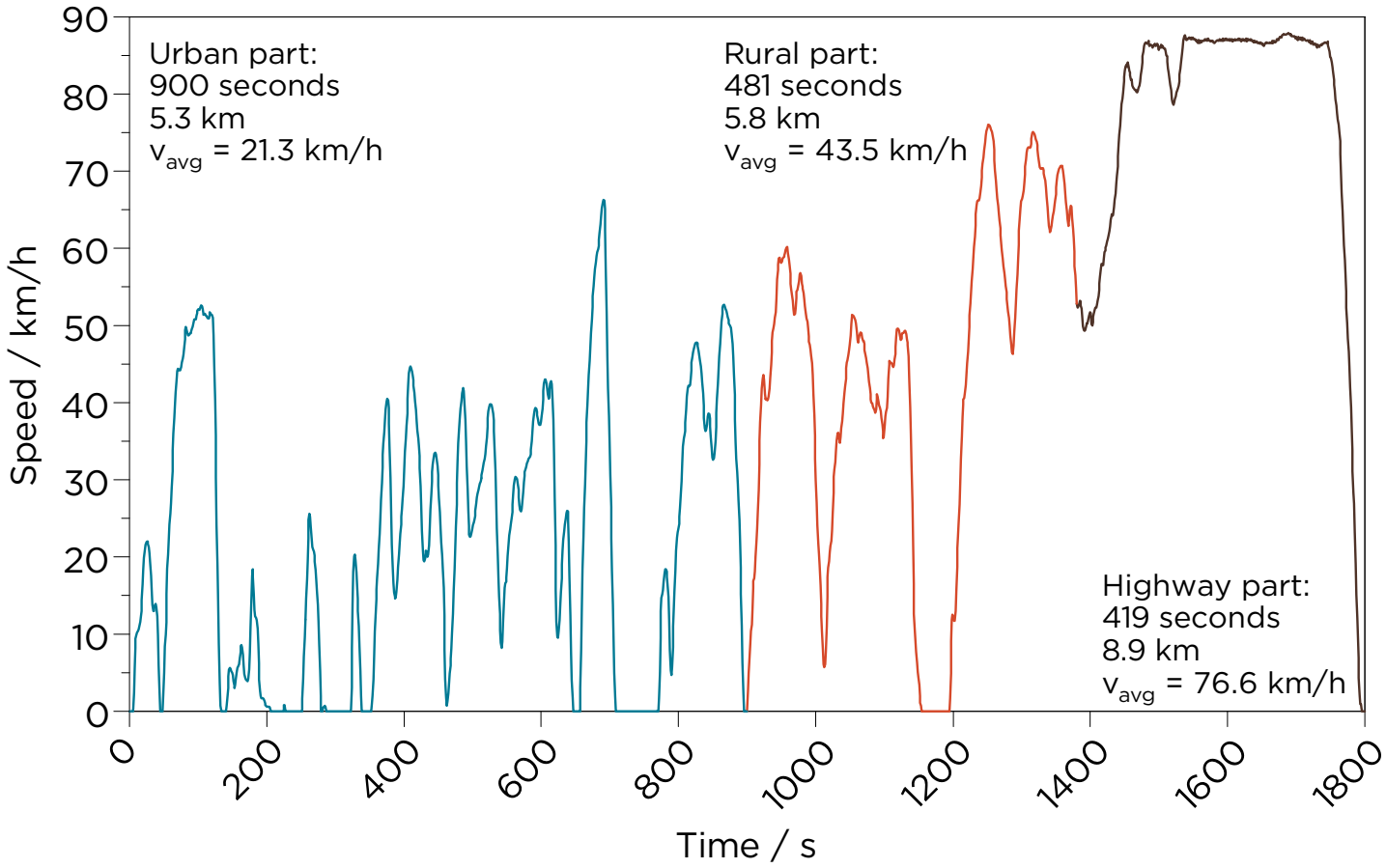
- The WHVC is based on data from trucking operations in a number of countries (Australia, EU, Japan and the US) and is designed to cover a wide range of HDV driving situations.

- The WHVC consists of three segments: an urban segment with transient stop-and-go driving, a rural segment that incorporates higher speeds, and a final motorway segment with steady state cruise driving.

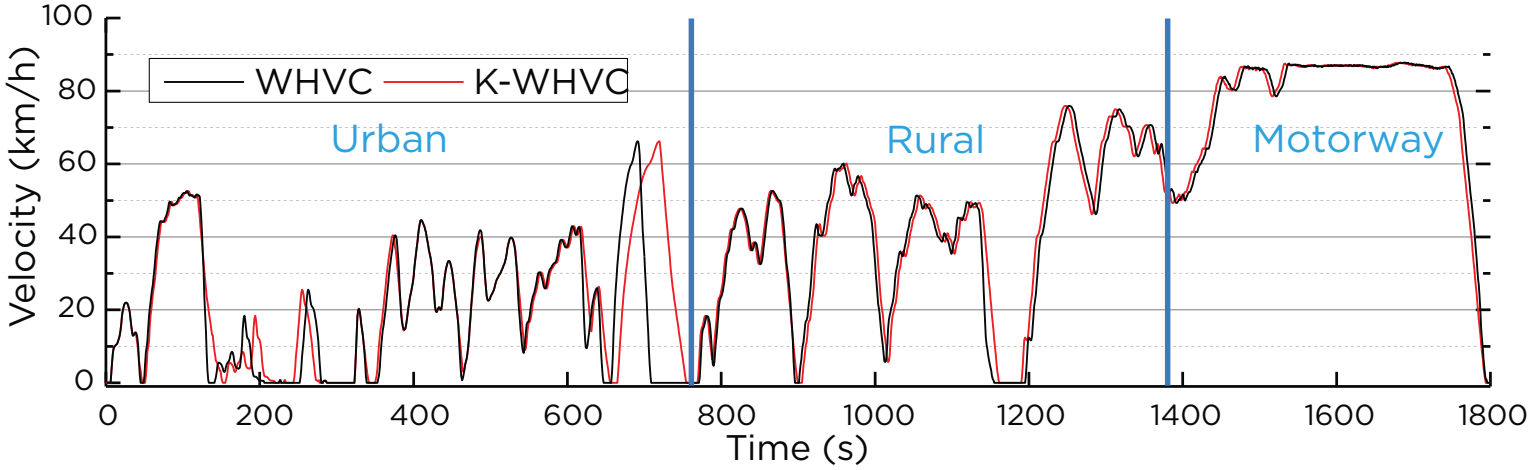
Steven, H. (2001). *Development of a World-wide Harmonised Heavy-duty Engine Emissions Test Cycle* (No. TRANS/WP29/GRPE/2001/2). ECE-GRPE WHDC Working Group. https://www.unece.org/fileadmin/DAM/trans/doc/2001/wp29grpe/TRANS-WP29-GRPE-42-inf02.pdf

Time-based: World Harmonized Vehicle Cycle (WHVC) 2/2

- The speed, and acceleration trace is fully defined by the cycle.
- Some vehicles will have an easy time following the speed trace, while some others won't be able to follow it.
- The set average speeds might not be representative of the local conditions.
- Some countries have modified the WHVC to reflect the local lower engine power-to-vehicle weight ratios.

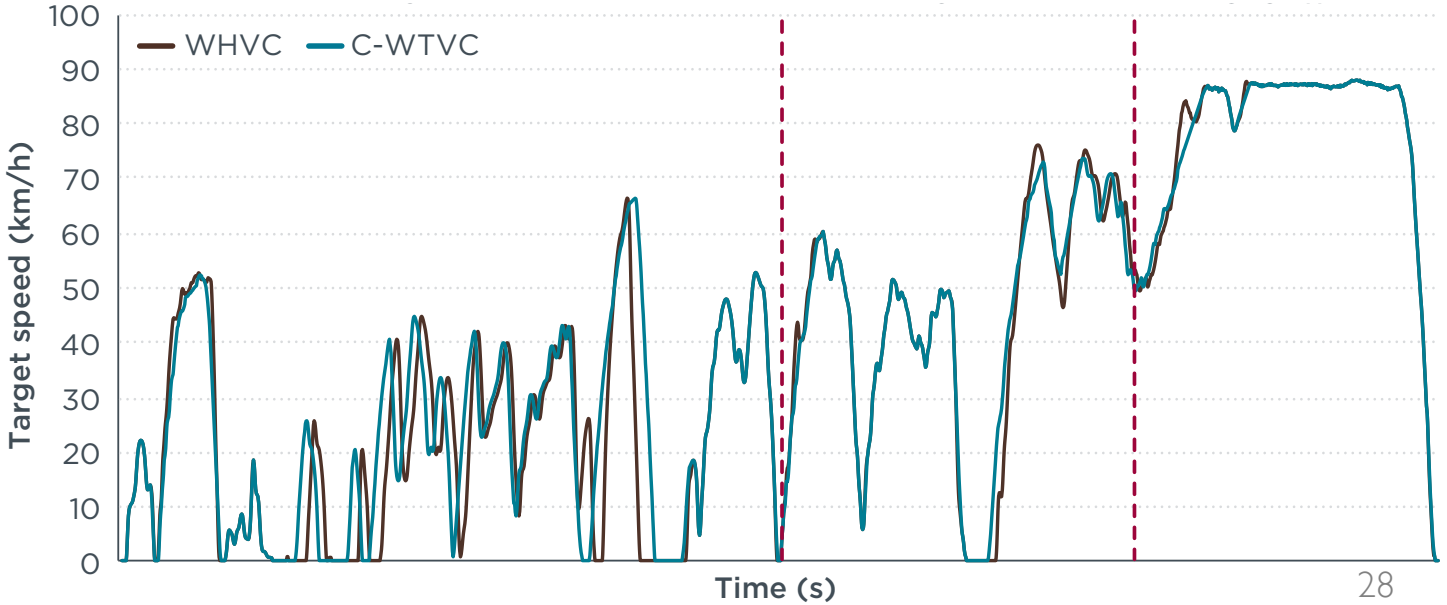


WHVC modifications for China and Korea

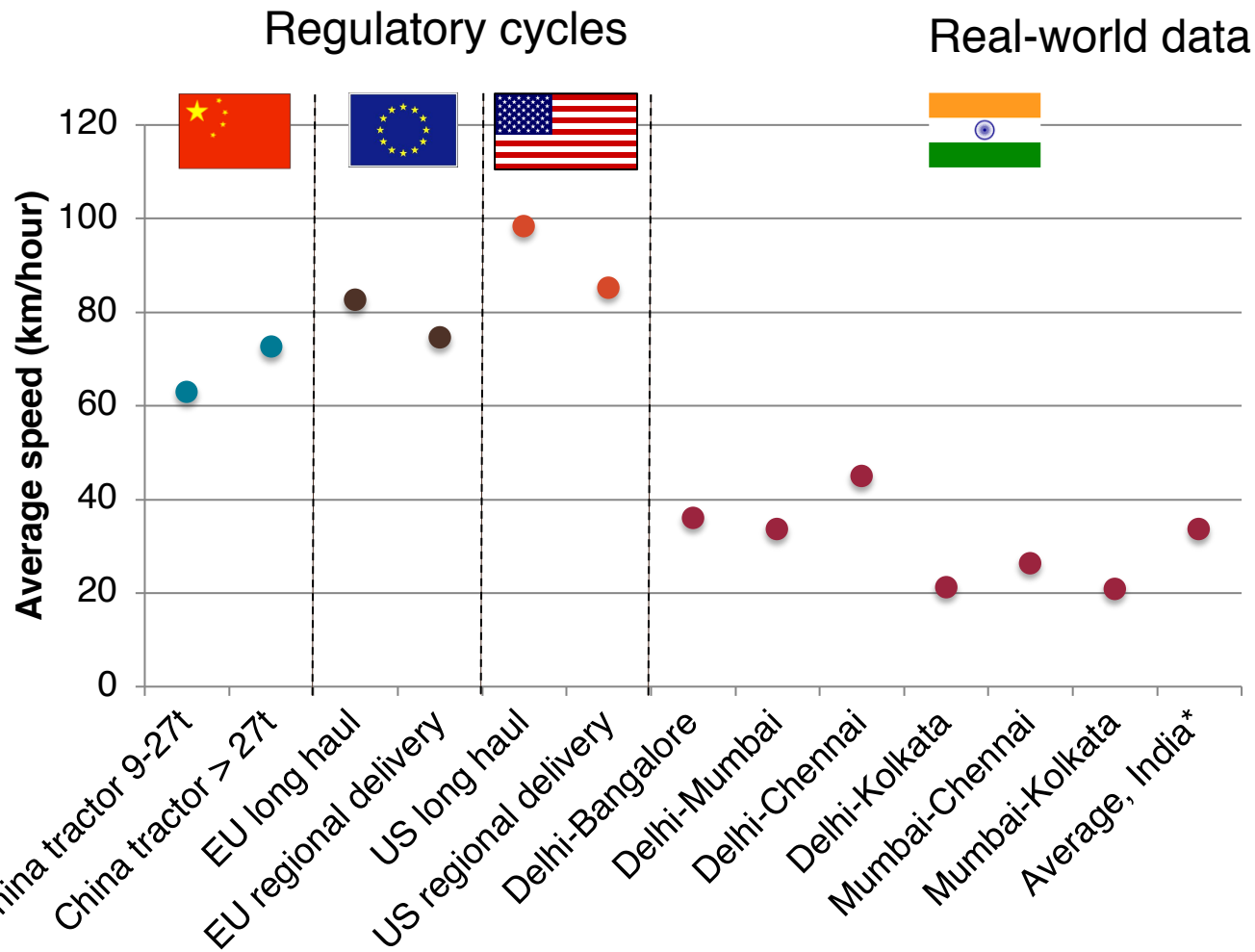


Seo, J., Park, J., Oh, Y., & Park, S. (2016). Estimation of Total Transport CO2 Emissions Generated by Medium- and Heavy-Duty Vehicles (MHDVs) in a Sector of Korea. *Energies*, *9*(8), 638. https://doi.org/10.3390/en9080638

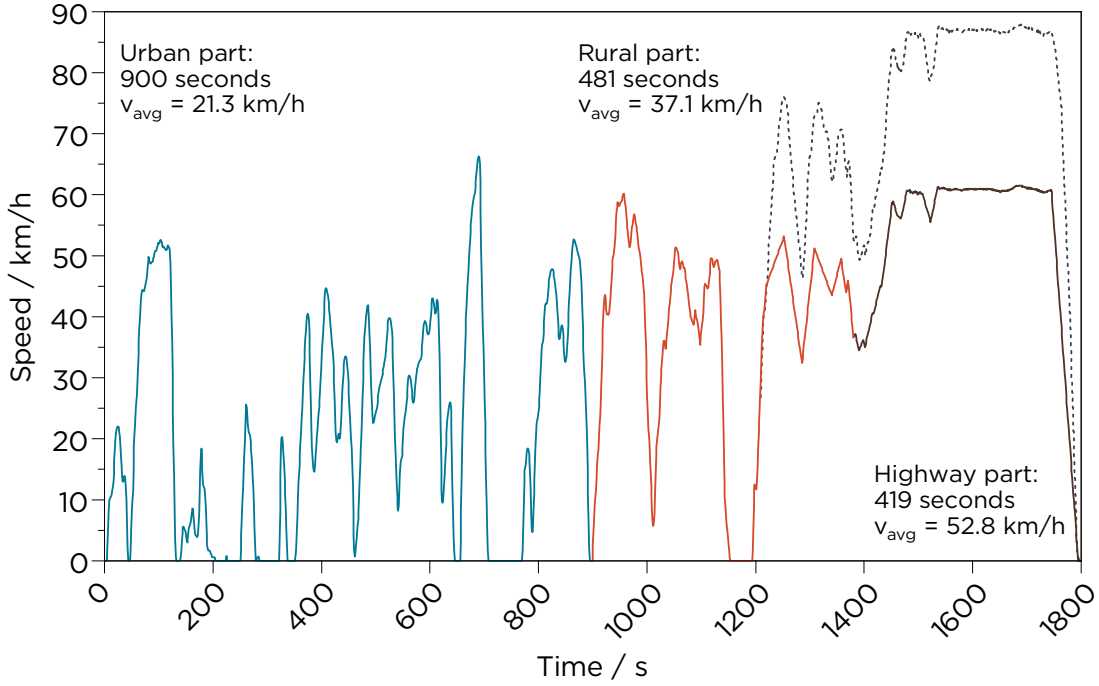
Delgado, O., & Li, H. (2017). *Market analysis and fuel efficiency technology potential of heavy-duty vehicles in China*. The International Council on Clean Transportation. www.theicct.org/publications/HDV-china-mkt-analysis-and-fuel-efficiency-tech-potential



Example: Average speeds are lower in India than other major markets



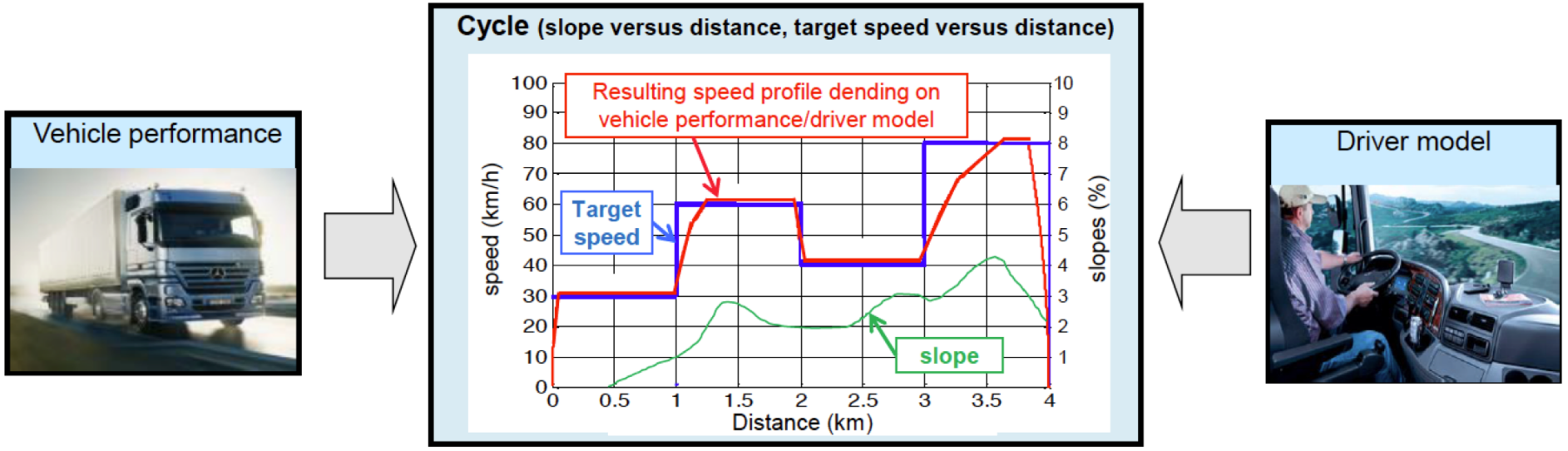
ICCT's version of a modified WHVC for fuel consumption research in India



* Average speed from surveys of 28 major trucking routes in India
Source: TCI-IIMC (2016) Operational efficiency of freight transportation by road in India. 3rd edition.

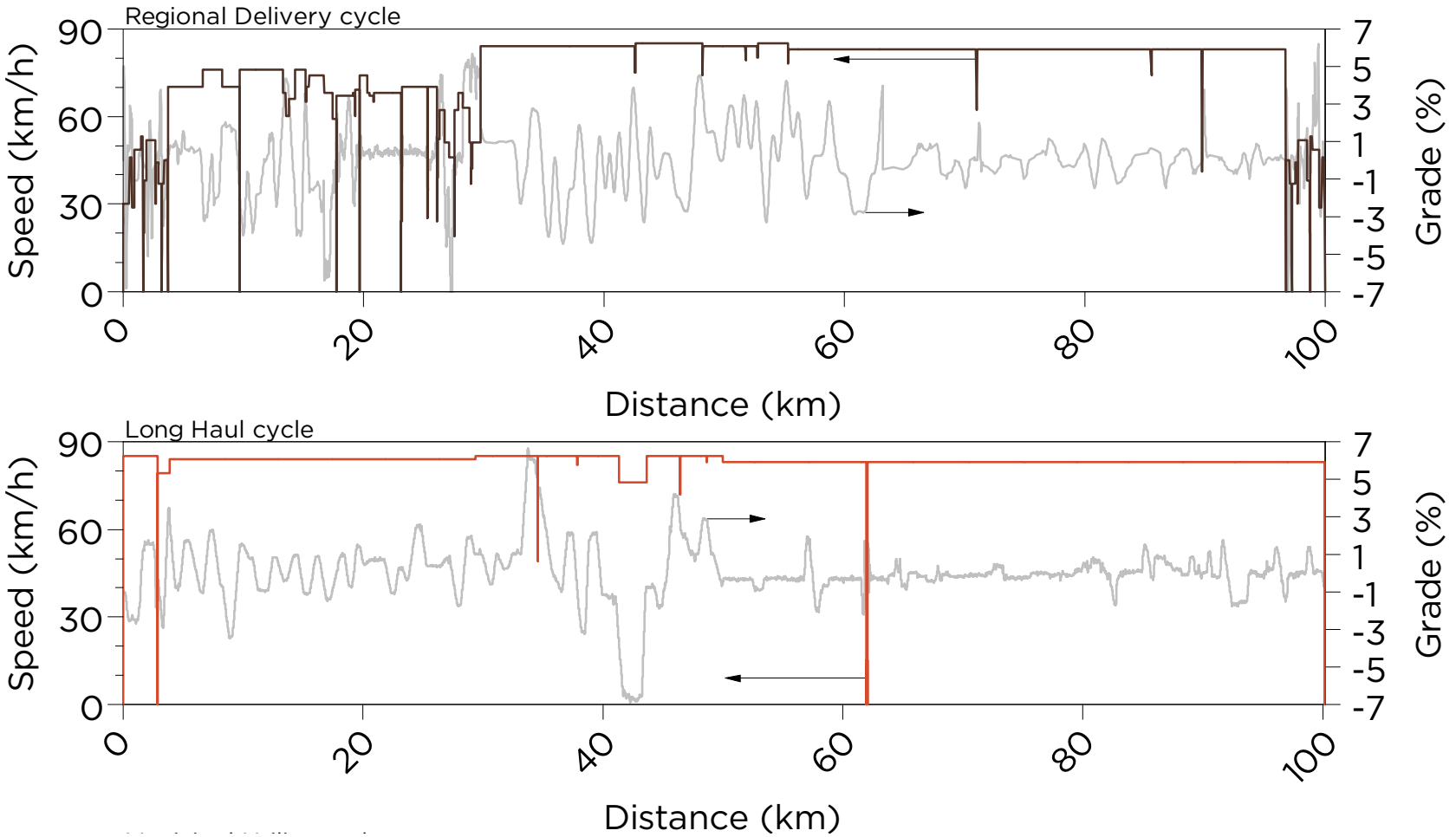
Distance based, target speed cycles in the EU

- Duty cycle is defined as routes. That is, road grade profiles and a desired target speed as a function of distance.
- The actual driven speed profile is a function of the vehicle technical specifications and the driver model.



Ralf Krukenberg (2017). ACEA's HDV White book extract with updates 2017 and amendments. Sao Paulo, Sept 5th, 2017. Pilot ACEA TF1

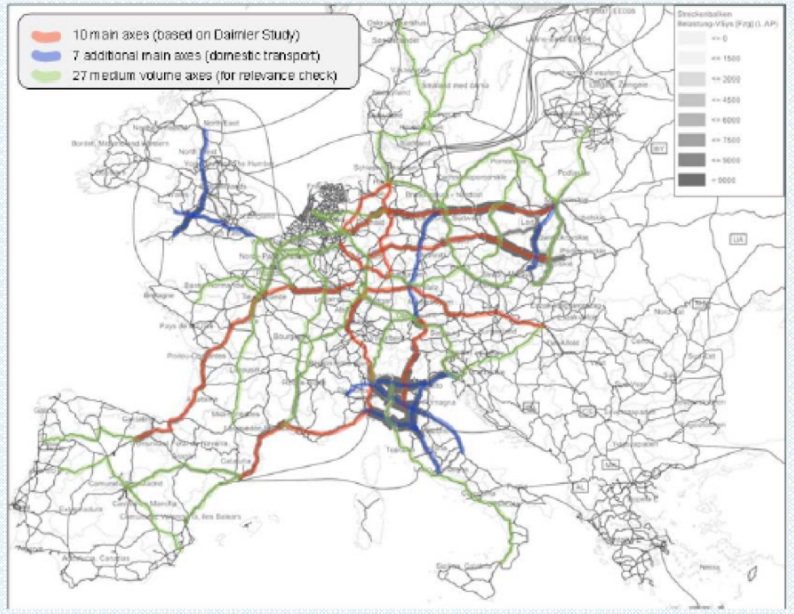
EU's Regional Delivery and Long Haul cycles



Rodriguez, F. (2018). *Fuel consumption simulation of HDVs in the EU: Comparisons and limitations* (White Paper). The International Council on Clean Transportation. www.theicct.org/publications/fuel-consumption-simulation-hdvs-eu-comparisons-and-limitations

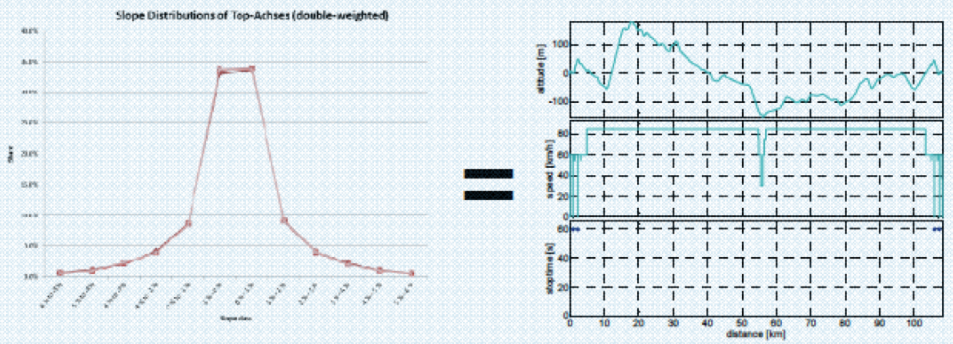
ACEA's validation for the Long Haul cycle for the EU

1. Derive representative routes for European long-haul road network based on statistical "goods flow" data



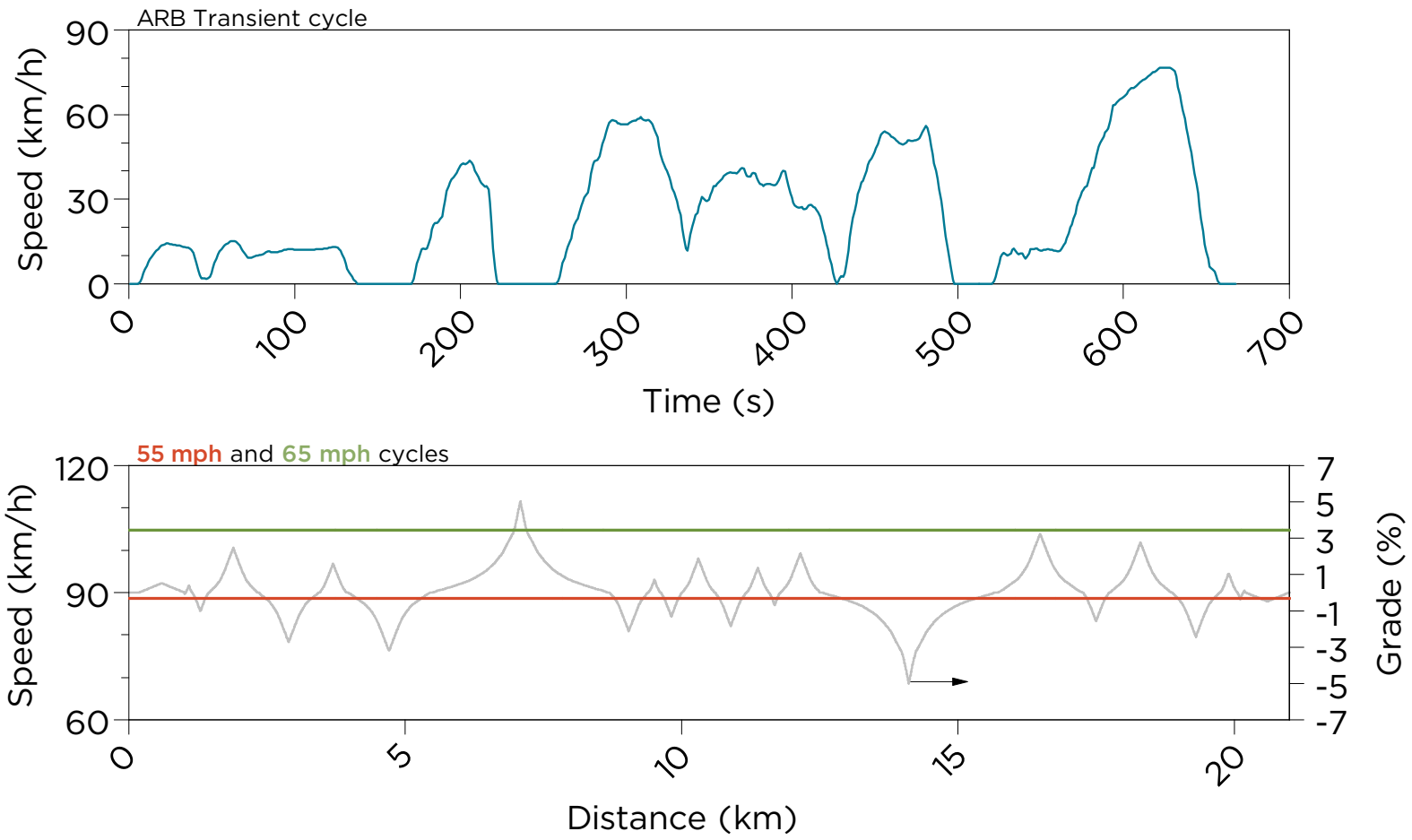
2. Measurement of slopes and speed profiles on representative routes (>10.000 km)

3. Compare speed and slope characteristics with long-haul cycle.
Make adaptions if needed.



Ralf Krukenberg (2017). ACEA's HDV White book extract with updates 2017 and amendments. Sao Paulo, Sept 5th, 2017. Pilot ACEA TF1

The GEM Phase 2 cycles are a combination of distance and time based cycles.



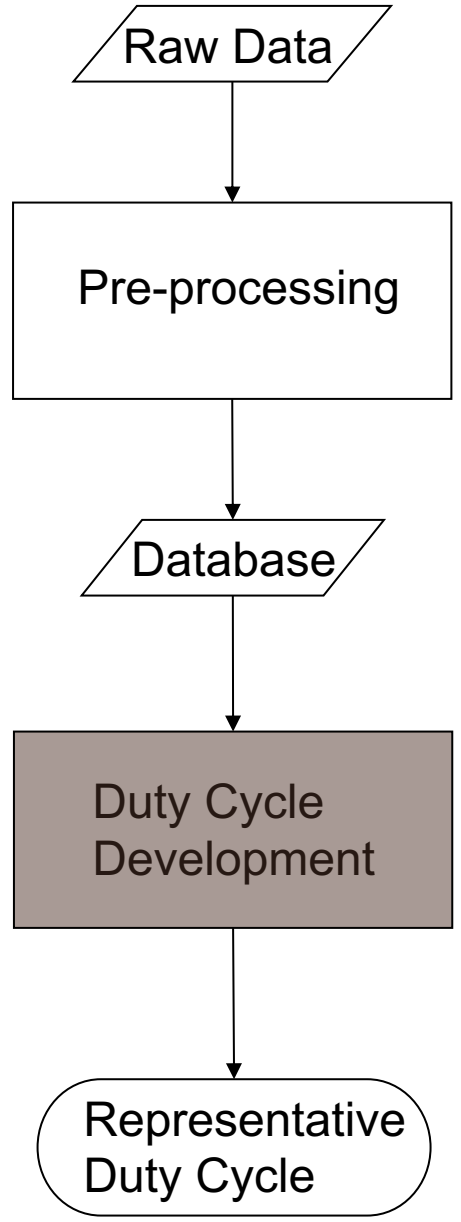
U.S. EPA, & U.S. DOT. (2016). *Final Rule: Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles–Phase 2* (Federal Register / Vol. 81, No. 206). https://www.gpo.gov/fdsys/pkg/FR-2016-10-25/pdf/2016-21203.pdf

ICCT has developed a work-flow for developing duty cycles based on in-use vehicle data

Duty Cycle Development:

6 steps:

1. Generates microtrips.
2. Generates N candidate cycles by adding randomly selected microtrips until minimum cycle time is achieved.
3. Calculates candidate cycles' metrics.
4. Calculates database metrics.
5. Compares candidates with in-use database.
6. Selects and save the 10 candidate cycles that best match the database.

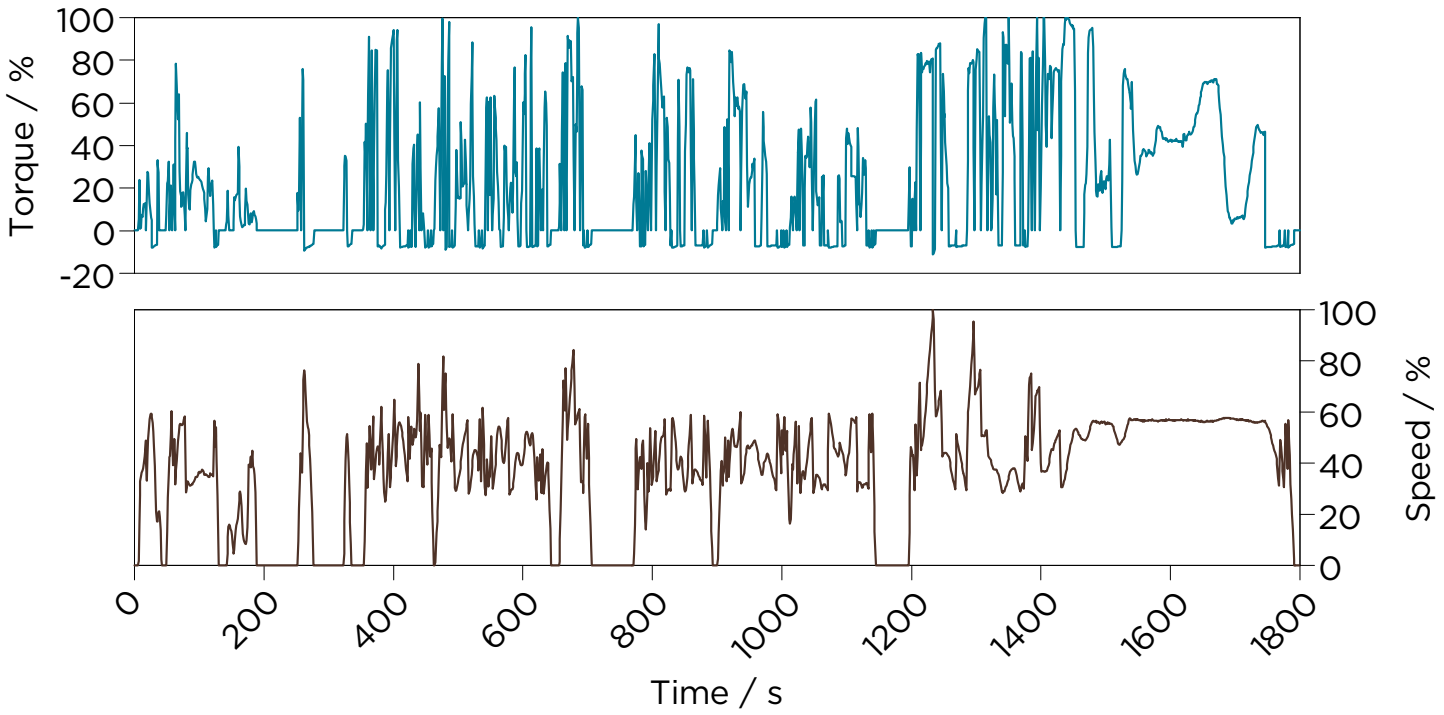


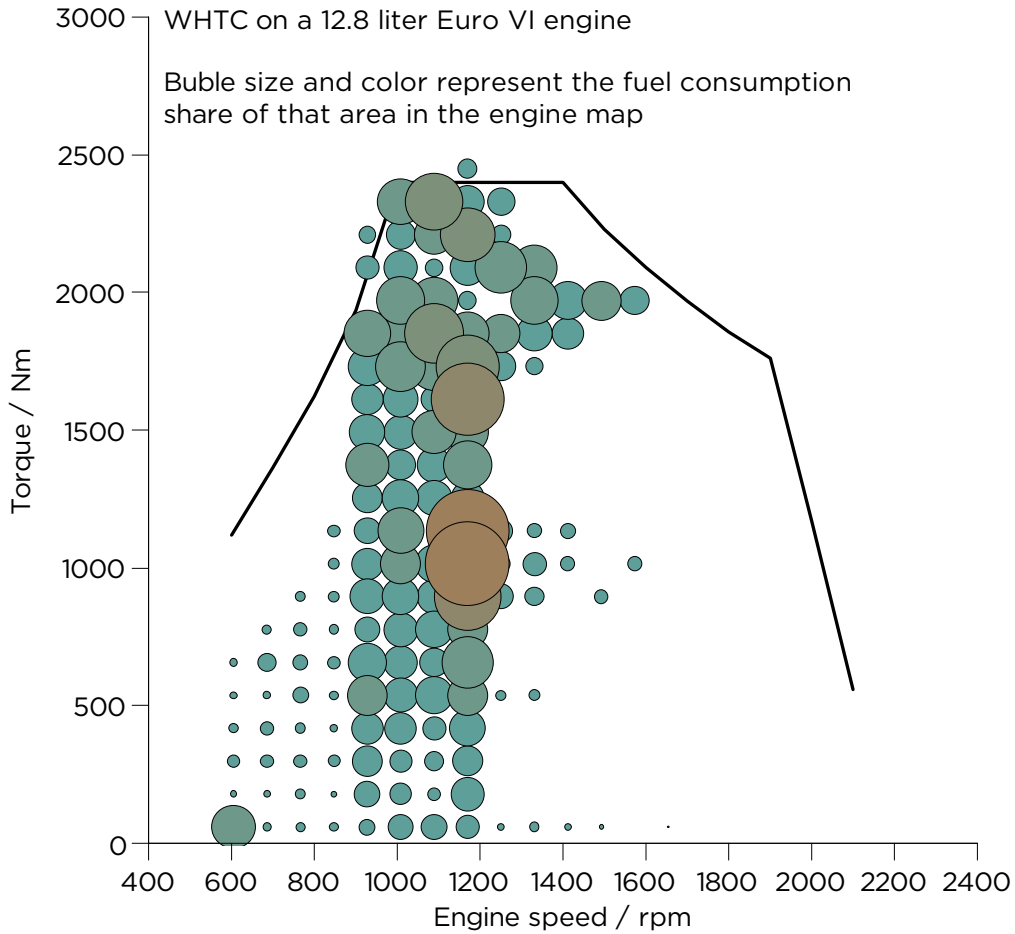
Duty cycles

Engine cycles

The duty-cycles for engine CO_2 certification can be derived directly from those developed for pollutant emission testing

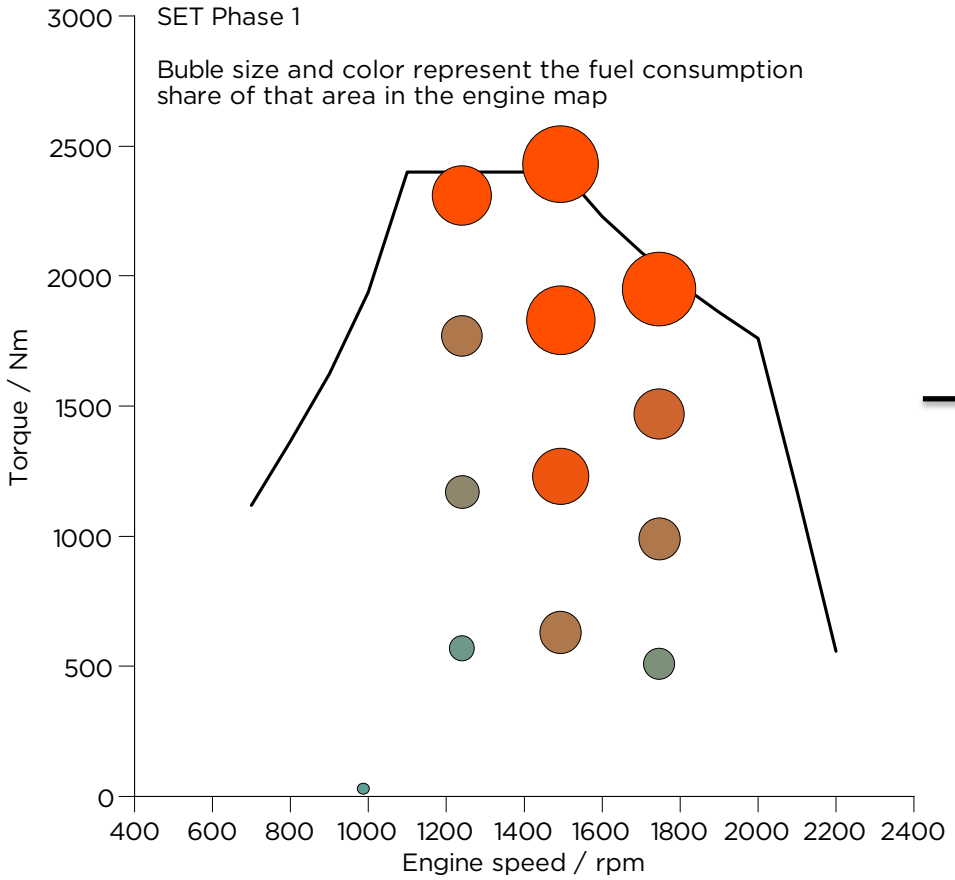
World Harmonized Transient Cycle (WHTC)



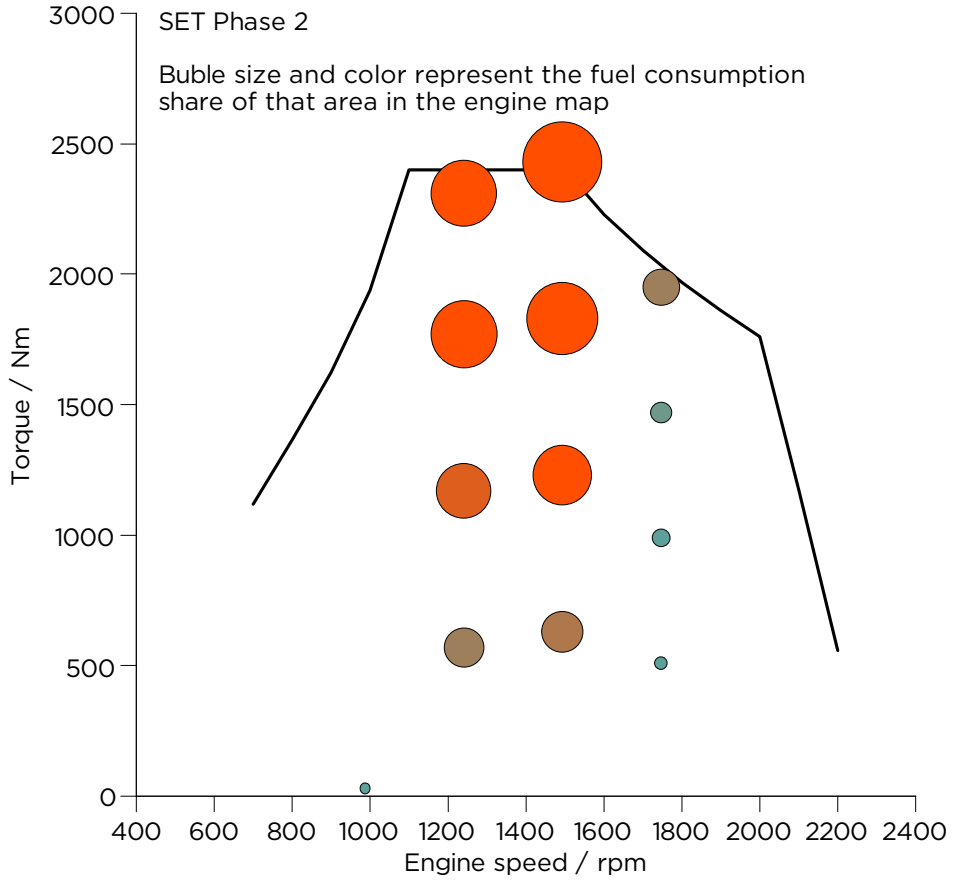


Adaptations of the existing cycles can be necessary

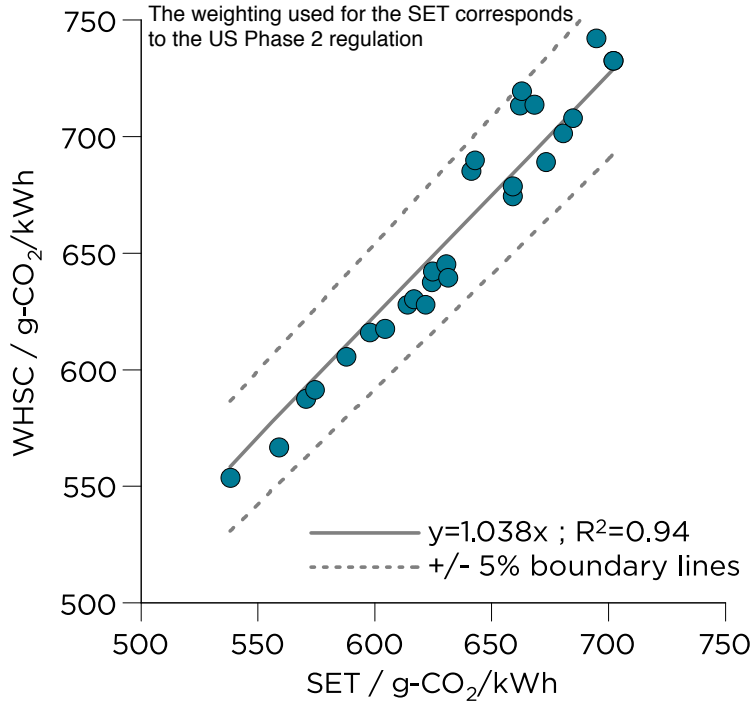
- Tractor engines in the US have limits over the SET steady-state cycle. For Phase 2, the SET weighting were revisited to reflect better low engine speed highway operation.

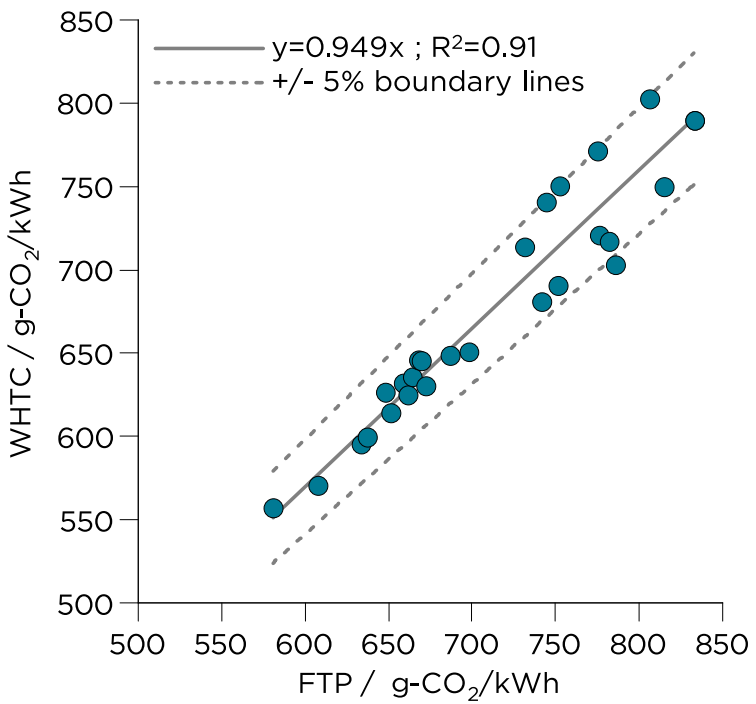


Higher weighting of lower engine speeds to reflect better long haul application



EU and US duty cycles can be correlated for CO_2 emissions





Comparison of 26 different engine maps over a simulated environment were used to estimate the correlation coefficients between the stationary WHSC and SET cycles, as well as between the transient cycles WHTC and FTP.

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Muncrief, R., & Rodríguez, F. (2017). *A roadmap for heavy-duty engine CO2 standards within the European Union framework.* The International Council on Clean Transportation. www.theicct.org/publications/roadmap-heavy-duty-engine-co2-standards-within-european-union-framework

Takeaway messages

- 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, nor duty cycle. 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.
- The development of duty cycles for fuel consumption certification must be a data-driven process. A good characterization of the vehicle fleet is necessary. Similarly, the topography and typical traffic conditions of the road network are also required.

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