Fuel efficiency and emissions of trucks in Germany
An overview

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Commissioned by
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

1. Background and Scope
2. Road Transport in Germany
3. Emission Regulation Heavy Duty Vehicles in Europe
4. Development of Fuel Quality - Europe/Germany
5. Emissions from heavy-duty trucks - Measurements and Modelling
6. Fuel efficiency and GHG emissions from heavy-duty trucks
7. Development of Transport, Emissions and Fuel Efficiency
8. Summary

Background & Scope

- The large increase of road freight transport in recent decades has made heavy-duty trucks a major source of greenhouse gas emissions as well as NO_x and PM air pollutant emissions. As a consequence, air pollution emission standards have been tightened constantly during recent years, esp. in the European Union and the USA. Furthermore, efforts are made to optimize fuel efficiency of heavy-duty engines and vehicles.
- IFEU was commissioned by GIZ to carry out an analysis and discussion of the road freight transport situation with heavy-duty trucks in Germany. This was done while considering transport developments and related emissions and energy consumption.
- The objective of this analysis is to illustrate the efforts made in Germany and Europe to reduce air pollution and greenhouse gas emissions from road freight transport, to highlight German experiences and to outline conditions for successful reductions of air pollution and greenhouse gas (GHG) emissions from increasing road freight transport.
- The study focuses on long-haul trailer trucks with a maximum vehicle weight of 40 metric tons as the by far most important size class in road-freight transport in Germany.

Background

- Goods transport increasing worldwide
- Heavy Duty Vehicles (HDV) with relevant contribution to air pollutants and greenhouse gases
- Fuel quality and emissions standards help to reduce environmental impacts

Scope

- Lessons from experiences with increasing goods transports in Germany
- Describe the situation of heavy-duty trucks in Germany considering transport and emissions
- Give an outlook of the future

Road transport in Germany I

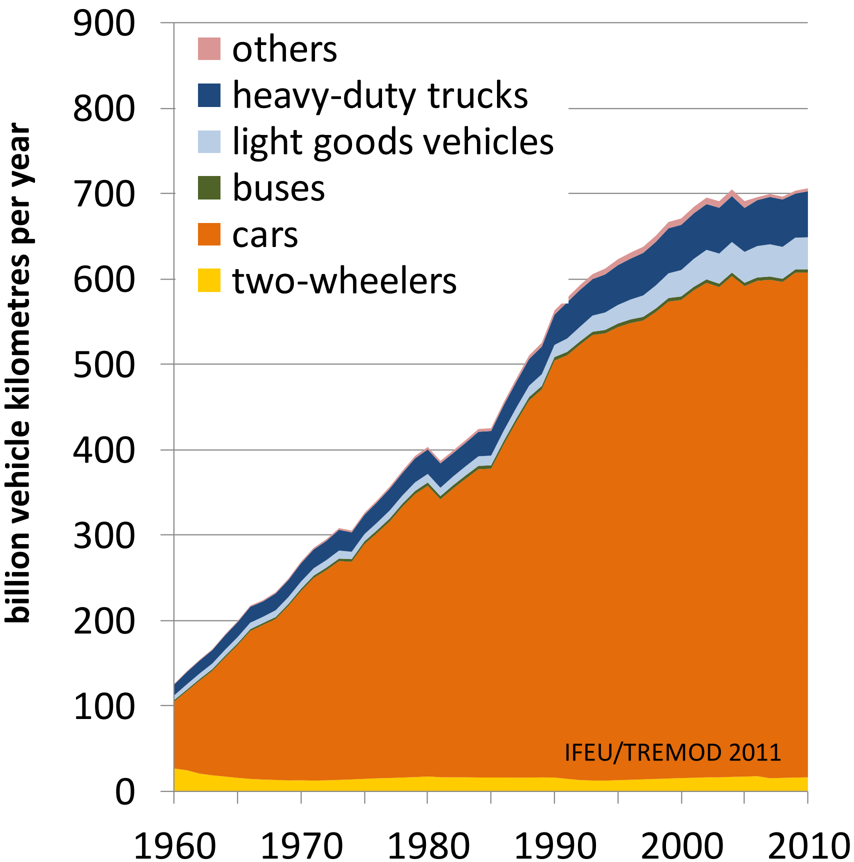
- Road transport has been greatly increasing in recent decades. In Germany road transport mileages today are more than 5 times higher compared to 1960. Concurrently, energy consumption and related (GHG) emissions have increased significantly.
  - The highest contribution to energy consumption in road transport comes from passenger cars (68% in 2010). In recent years though their energy consumption declined slightly despite ongoing mileage increases due to considerable efficiency gains.
  - In contrast, heavy-duty trucks contributed about 23% to energy consumption while having only 8% mileage share and their energy consumption is still on the rise. Hence road freight transport by heavy-duty trucks carries an increasing importance for fuel consumption and GHG emissions from road transport.
- Air pollutant emissions also increased strongly with increasing road mileages over several years. However, the implementation and continuous tightening of emission regulations for all road vehicles have led to a strong decrease of important pollutants during the last 20 years, despite ongoing transport growth.
  - Especially the introduction of three-way catalytic converters has led to high reductions of NO_x emissions from gasoline-fuelled light-duty vehicles.
  - Diesel-fuelled heavy-duty trucks have high NO_x and diesel particle emissions. In the past, they contributed up to 46% to NO_x emissions and 61% to particle emissions from road transport in Germany. Since the mid-nineties, their emissions were strongly reduced as a result of European emission legislation. Despite that they still contributed 39% to NO_x and 23% to exhaust particle emissions in 2010.

Road transport in Germany II

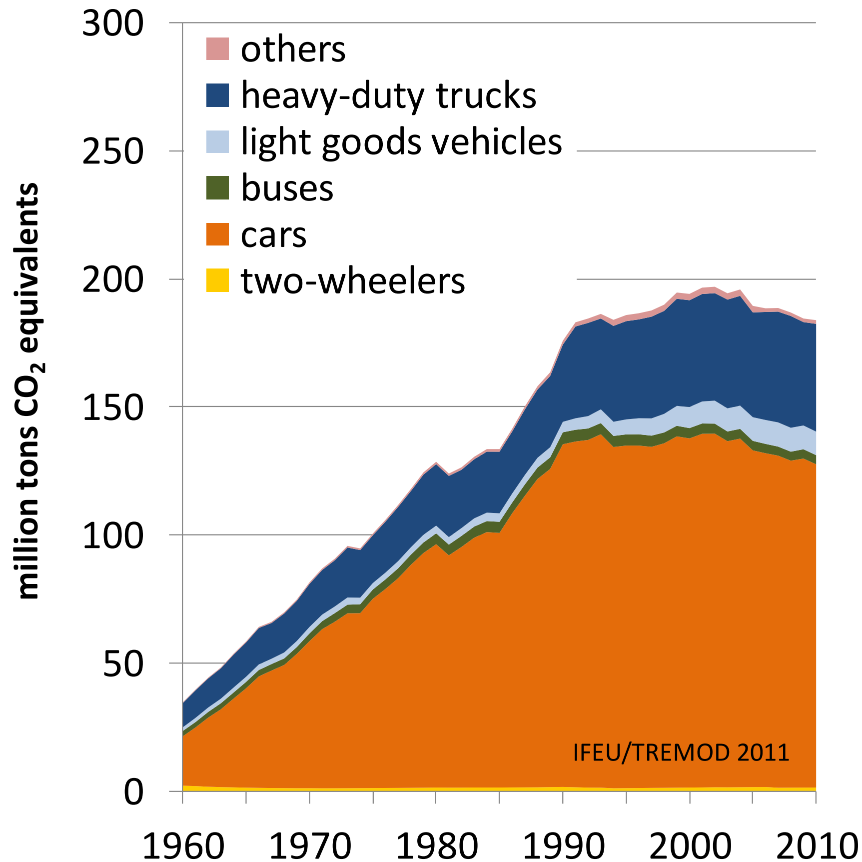
- In the last 15 years, transport performance (transport volumes x transport distances) with heavy-duty trucks (>3.5 – 40 metric tons gross vehicle weight) increased by 55%.
- This increase was mainly caused by increasing transport performances of long-haul trailer trucks with a maximum vehicle weight (empty truck + load) up to 40 tons. With a share of 88% on transport performance in 2010, they are the dominating size class in Germany.
- As the increasing freight volumes were mostly transported by 40-ton trucks, which have considerably higher payloads than smaller heavy-duty trucks, total road mileages of heavy-duty trucks increased by only 16% from 1995 to 2010.
- In 2010 40-ton trucks had a 63% mileage share and, thus, where the dominating size class in road transport.

High increase of truck transport leads to increasing energy consumption and greenhouse gas emissions…

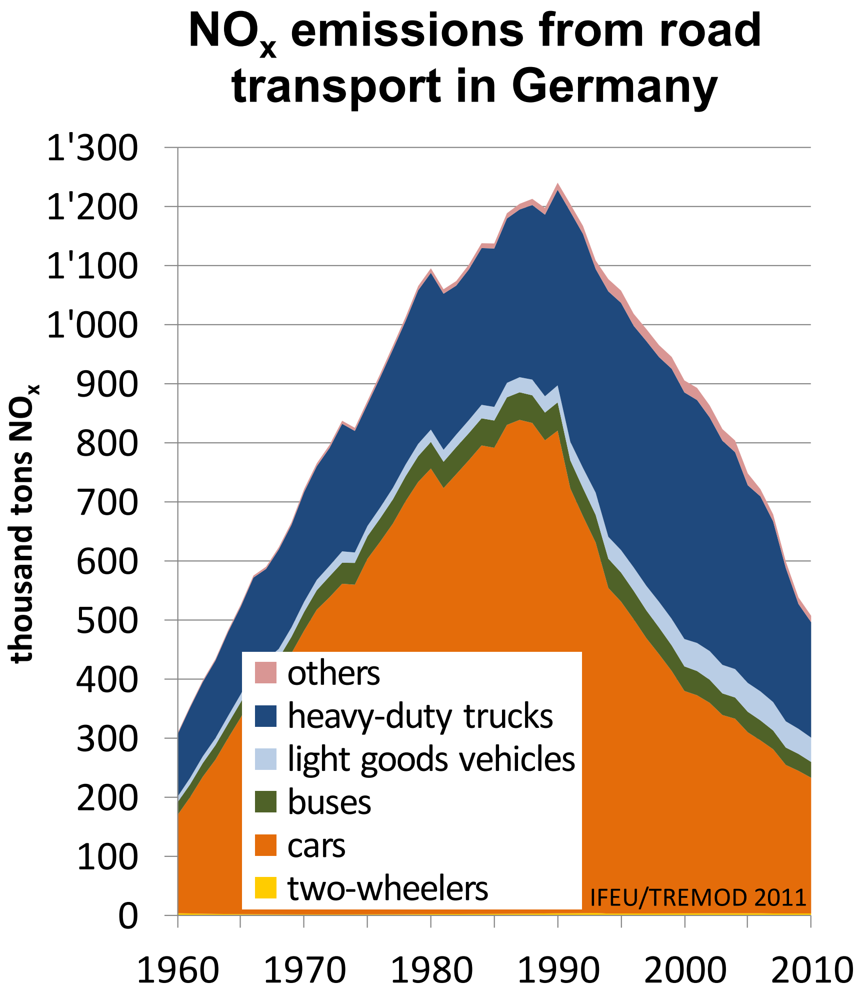
Annual mileage of road transport in Germany

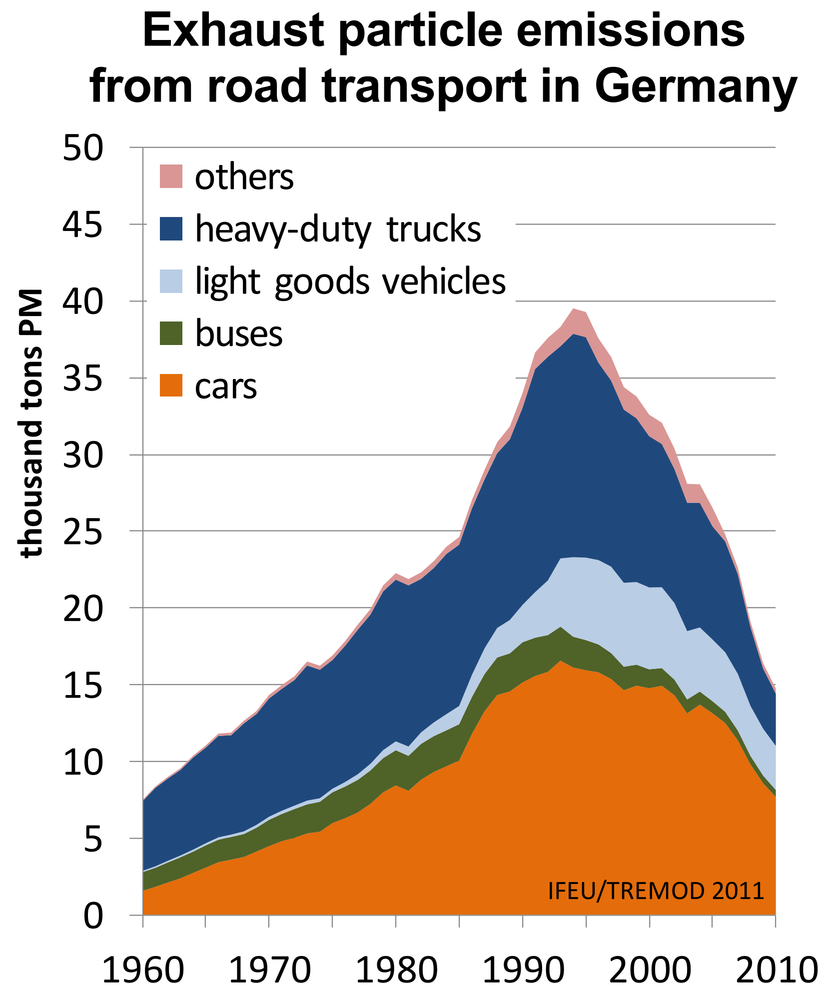


GHG emissions from road transport in Germany

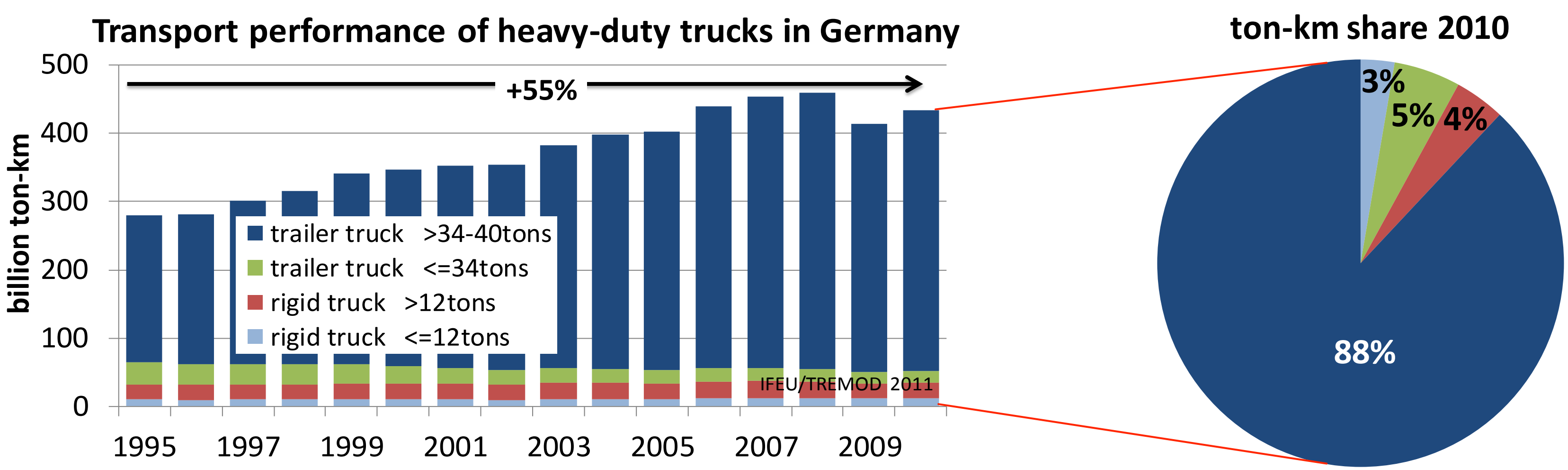


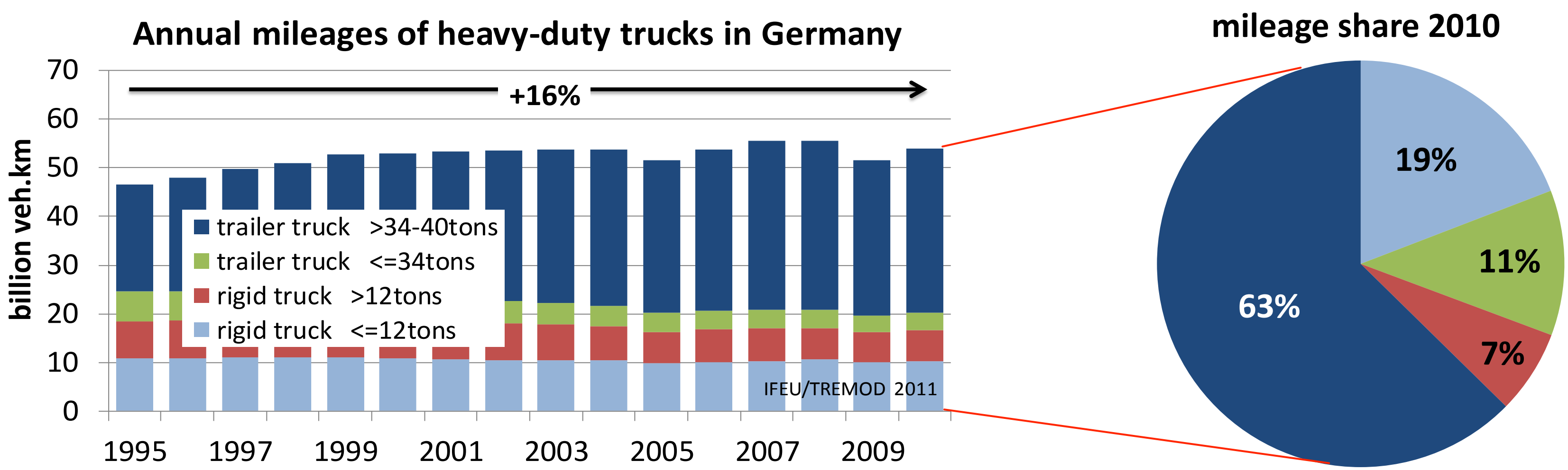
…contribution from heavy-duty trucks on NO_x and PM emissions from road transport on a high level





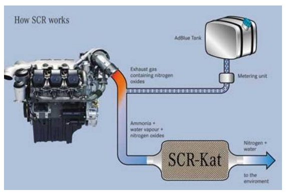
Trailer Trucks > 34 tons gross vehicle weight (mostly 40 t) have a high and increasing share on ton-km and mileage





How can specific emissions and fuel consumption of road-freight-transport with heavy-duty trucks be reduced?

➔ Exhaust emission treatment and energy-saving technologies



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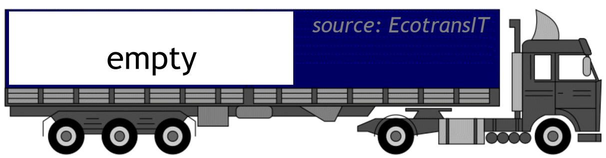
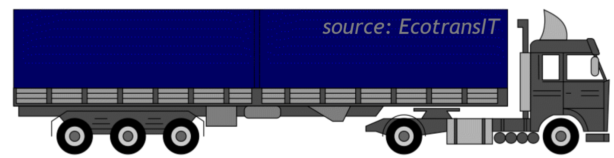
➔ Increase of vehicle load factors





➔ Larger vehicles with higher payloads

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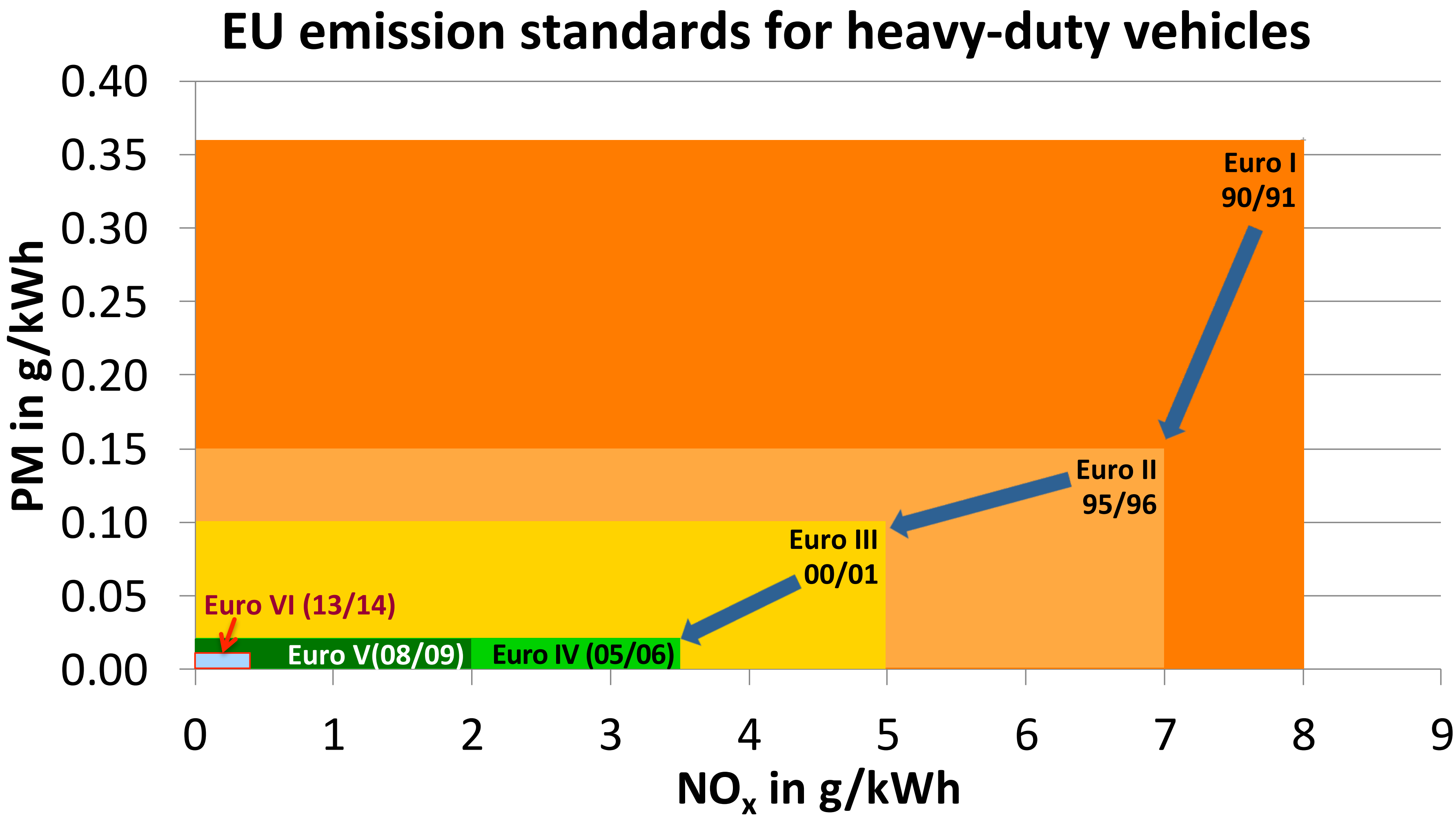
Emission regulation in Europe

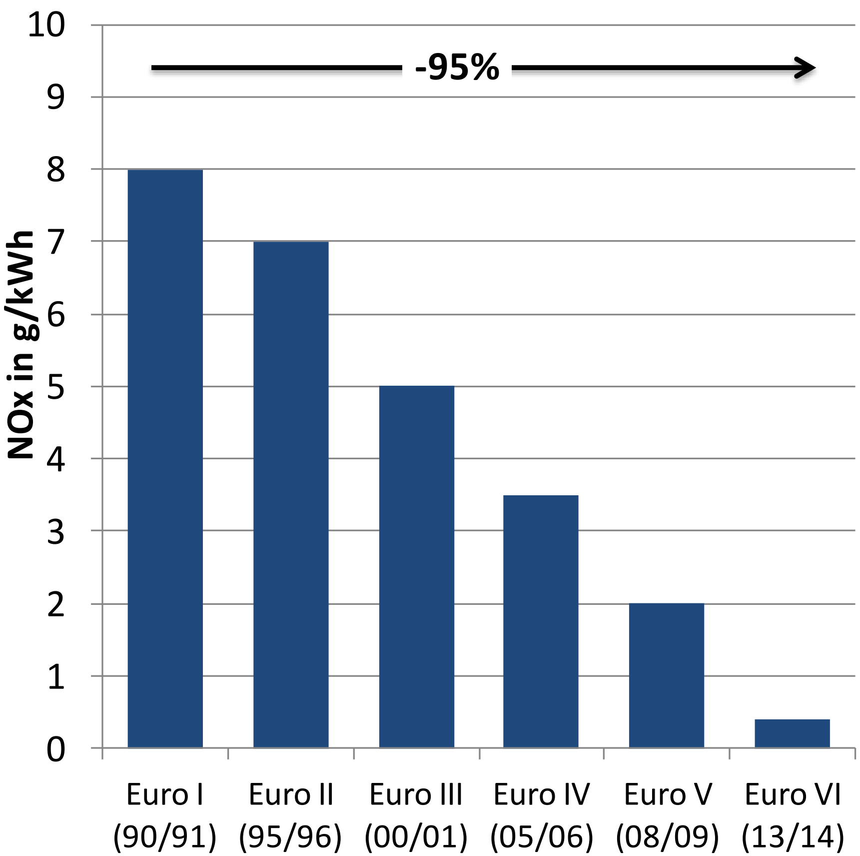
- Harmonized exhaust emission regulation for heavy-duty vehicles in European Union started with Euro I (valid from 1992 for new engine types and 1993 for all new sales). The so far most ambitious emission standard Euro VI will become mandatory in 2013/2014. From Euro I to Euro VI, emission limit values for NO_x were reduced by 95% and by 97% for diesel particles.
- In addition, the test cycles for type approval procedures have been refined.
  - Up to the Euro II emission standard, a 13-mode steady-state diesel engine test cycle intro-duced by ECE Regulation No.49 (1988) and then adopted by the EEC [EEC Directive 88/77] had been used for type approval emission testing of heavy-duty highway engines.
  - Since the Euro III stage (2000), the ECE R-49 has been replaced by the European Stationary Cycle (ESC), a 13-mode, steady-state procedure, plus the European Transient Cycle (ETC), based on real road cycle measurements of heavy duty vehicles (source: www.dieselnet.com).
  - With Euro VI, newly developed world harmonized stationary and transient test cycles (WHSC, WHTC) become mandatory.
- European emission standards up to Euro III were achieved with internal engine optimization measures. With Euro IV and V, two different exhaust after treatment systems are applied to meet the NO_x and PM emission limits:
  - Exhaust gas recirculation (EGR) + diesel particulate filter (DPF).
  - Selective catalytic reduction (SCR) without DPF
  - Both technologies require the use of diesel fuel with low sulphur content.
- With the coming Euro VI emission standard which demands further strong reductions of NO_x and PM emissions, the application of SCR systems and DPF is expected.

Exhaust gas emission legislation since 1992/93: High reduction of NO_x and PM emissions

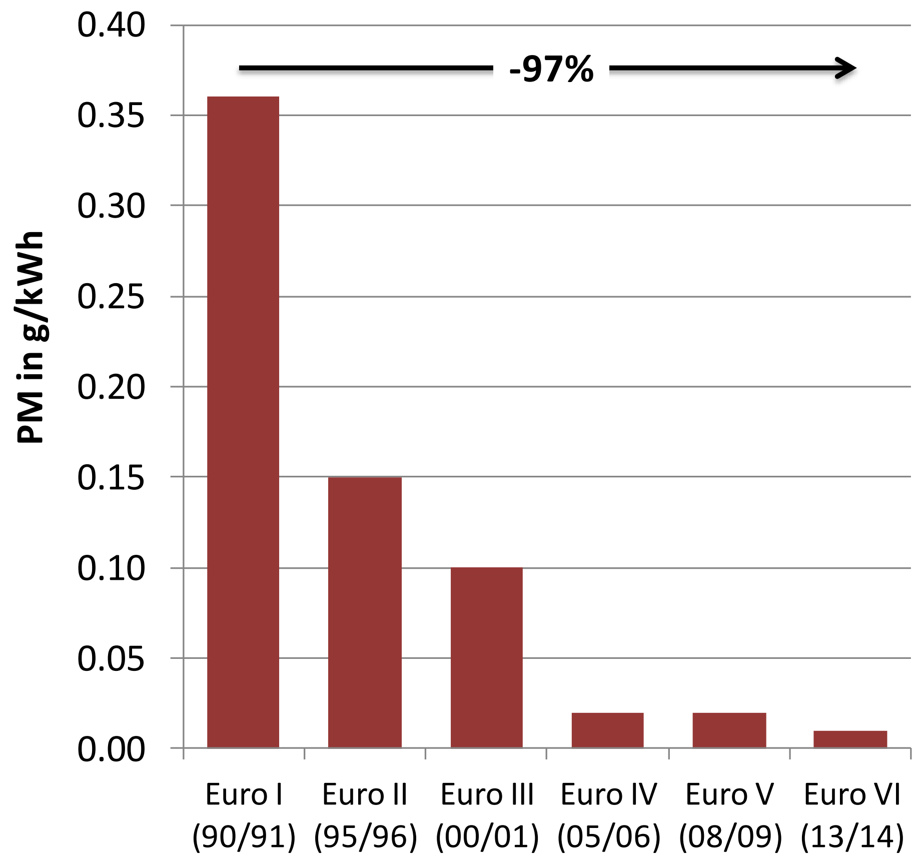


Exhaust gas emission legislation since 1992/93: High reduction of NO_x and PM emissions

NO_x emission standards for heavy-duty vehicles in EU



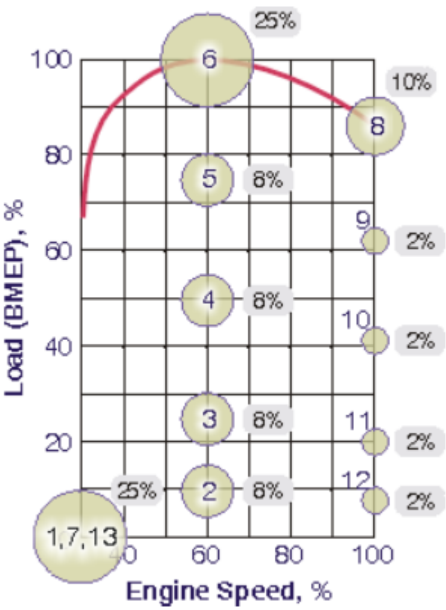
Particle emission standards for heavy-duty vehicles in EU



Test Cycles for type approval have been refined from stationary tests to transient cycles

Euro 0-II

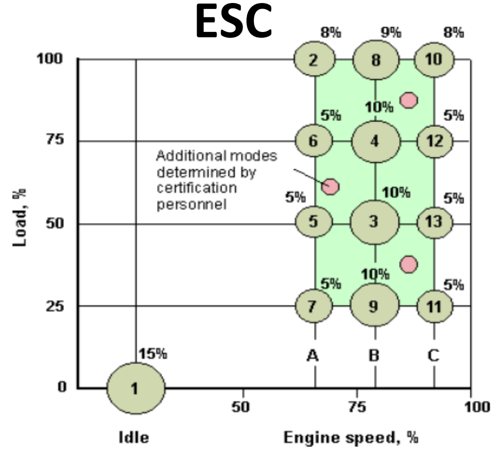
ECE R49



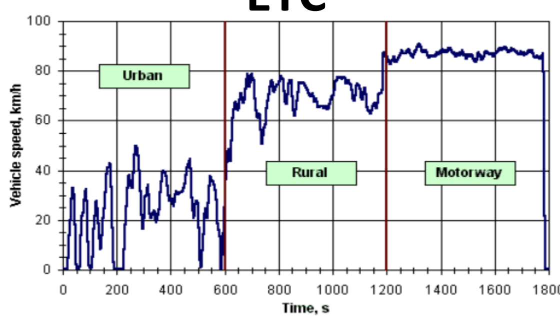
Source: dieselnet.com

Euro III-V

ESC



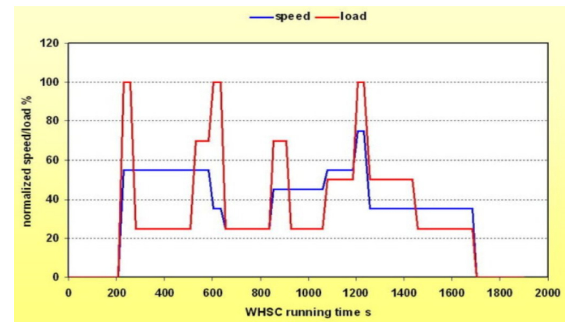
ETC



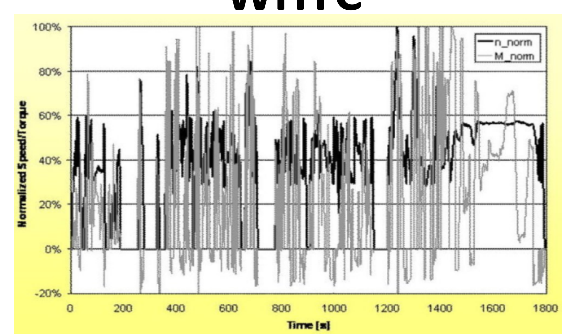
Source: dieselnet.com

Euro VI

WHSC

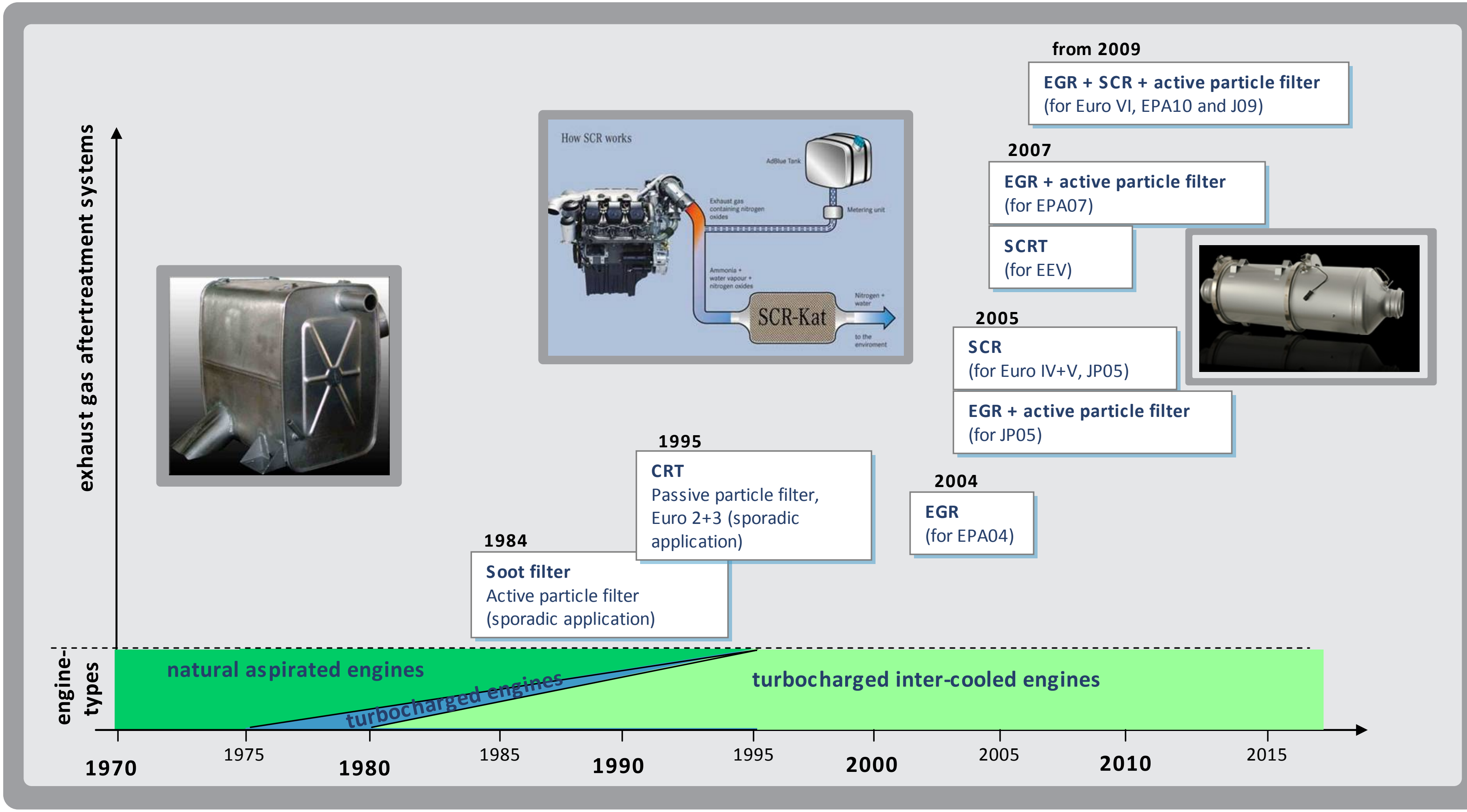


WHTC



Source: Emitec

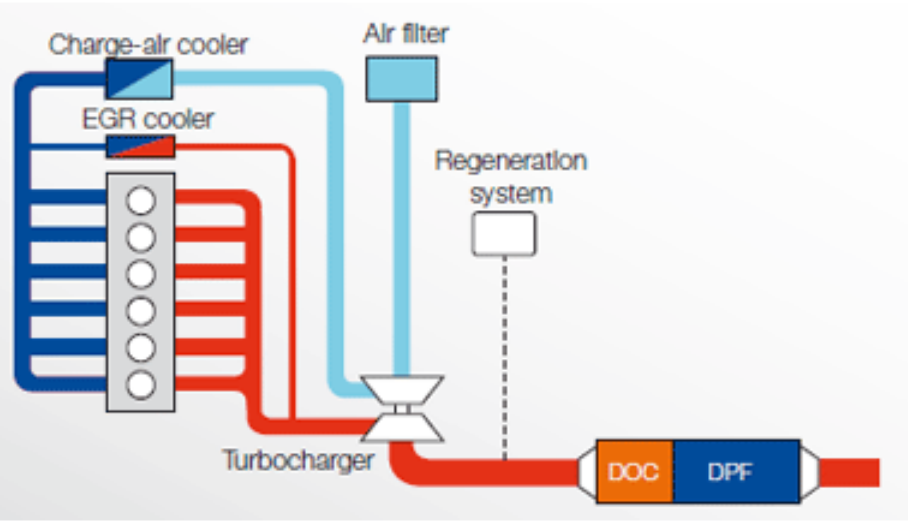
Aftertreatment: From exhaust silencer to chemical plant....



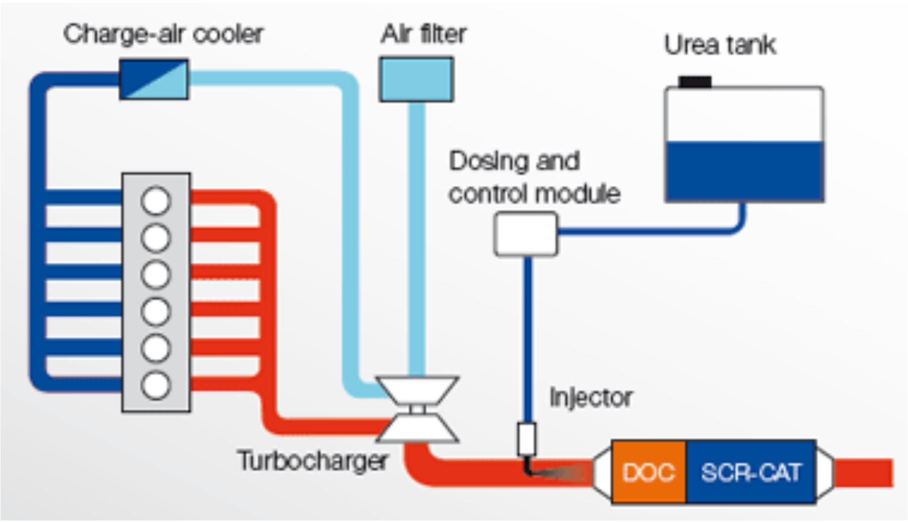
Source: Holloh Daimler, 2008

EGR, Particle Filters and SCR are advanced technologies for reducing exhaust emissions

EGR+DPF



SCR



Source: CLAAS POWER SYSTEMS

Euro IV/V: two alternative exhaust aftertreatment systems.

- Exhaust gas recirculation (EGR) + diesel particulate filter (DPF).
- Selective catalytic reduction (SCR), no DPF

Euro VI: DPF and SCR expected

EGR more simple - SCR additional efficiency benefits

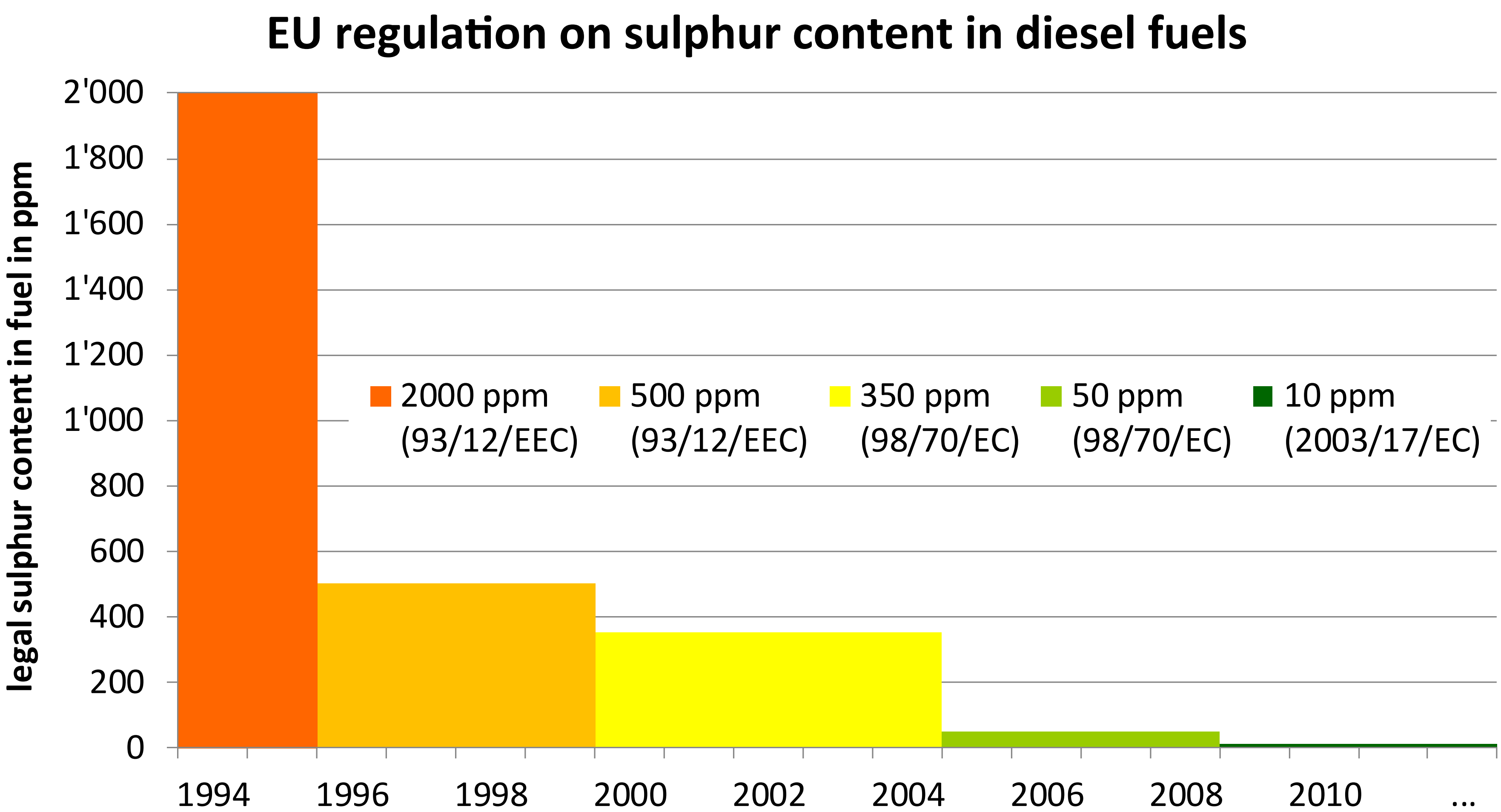
	EGR	SCR
Pros	- No additional equipment (extra tank) - No loss of payload and fuel capacity - No handling changes for haulier and drivers	- Simplicity of the system and possibilities for subsequent development (future standards) - No impact on maintenance and oil change intervals - Engine optimization can be focused on fuel efficiency
Contras	- Decreases power density, fuel efficiency - Potential engine durability and oil degradation issues (= shortened oil change intervals) - Engines are larger and possibly heavier, depending on power rating - Increases heat rejection, creating need for greater cooling capacity	- Additional urea tank reduces vehicle's payload and can lead to complications with bodywork assembly - Urea supply infrastructure needed - Urea has a tendency to harden at low temperatures (- 11°C) - Least effective in situations with low exhaust temperature (e.g. urban operations, stop+go) - Limited additional efforts for the driver

Sources: Vialtis 2005, FleetOwner 2008

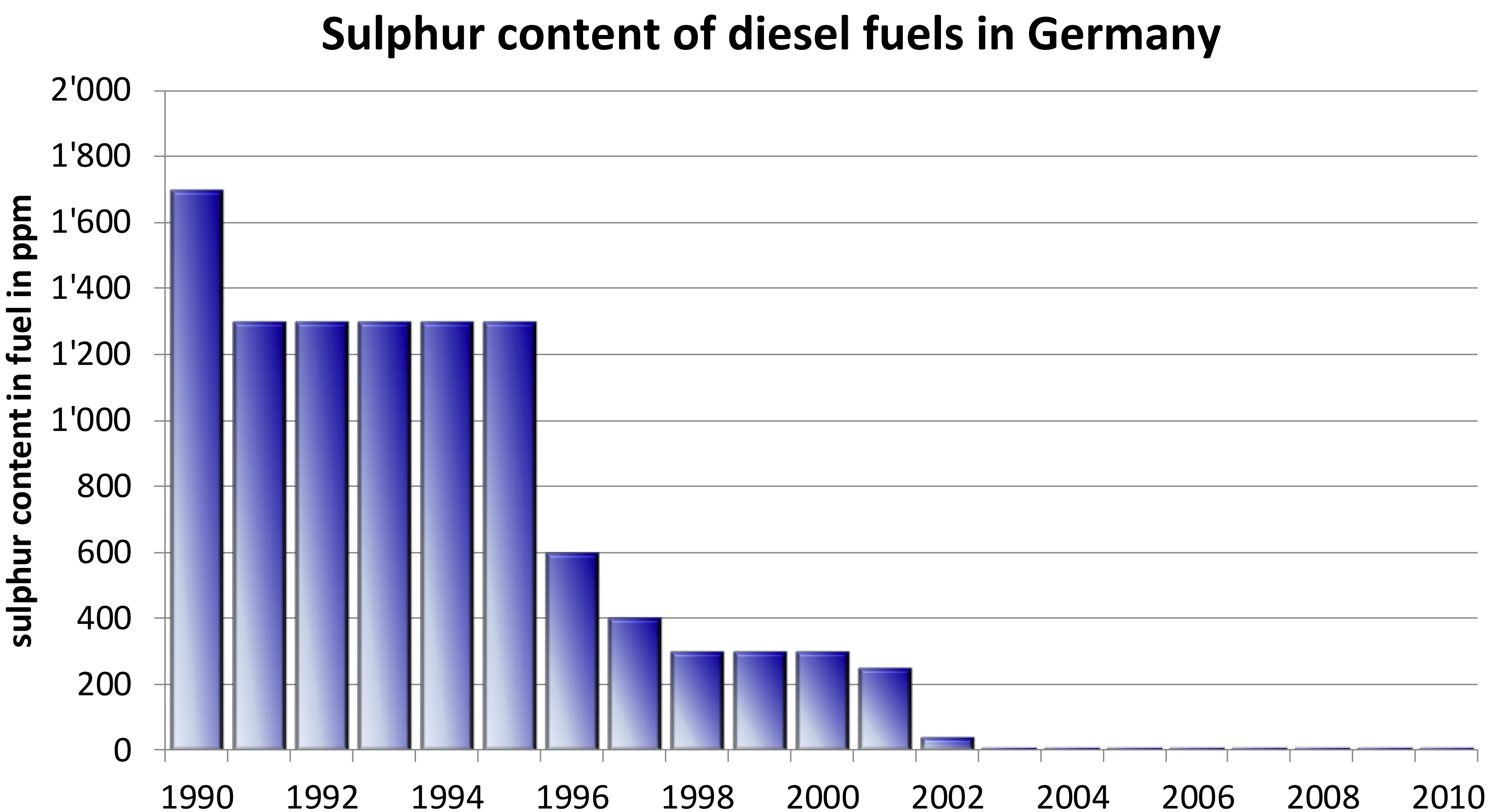
Fuel quality in Europe

- One important condition for the introduction of emission-reducing after treatment technologies with Euro IV and V was the regulation of diesel fuel quality – primary the reduction of the sulphur content.
- In the European Union, standards for fuel quality were first developed by the European Standards Organization (CEN) and adopted by European legislation. The first fuel standard for the sulphur content of diesel fuels was defined with council directive 93/12/EEC, setting limits of 2,000 ppm (from 1994) and 500 ppm (from 1996). These standards have been tightened with EU directives 98/70/EC and 2003/17/EC up to "sulphur-free" diesel with a maximum sulphur content of 10 ppm, obligatory as of 2009.
- Developments of fuel quality in Europe reflect the success of these fuel quality regulations. Sulphur content in diesel fuels was considerably reduced in recent years.
  - In Germany, diesel fuels were "sulphur-free" by 2003.
  - In the European Union, about half of all 27 EU countries had "sulphur-free" diesel in 2008. All other EU countries had average sulphur contents in diesel fuels of no more than 30 ppm.

EU regulation on sulphur content in diesel fuels - important condition for environmentally friendly vehicle technologies



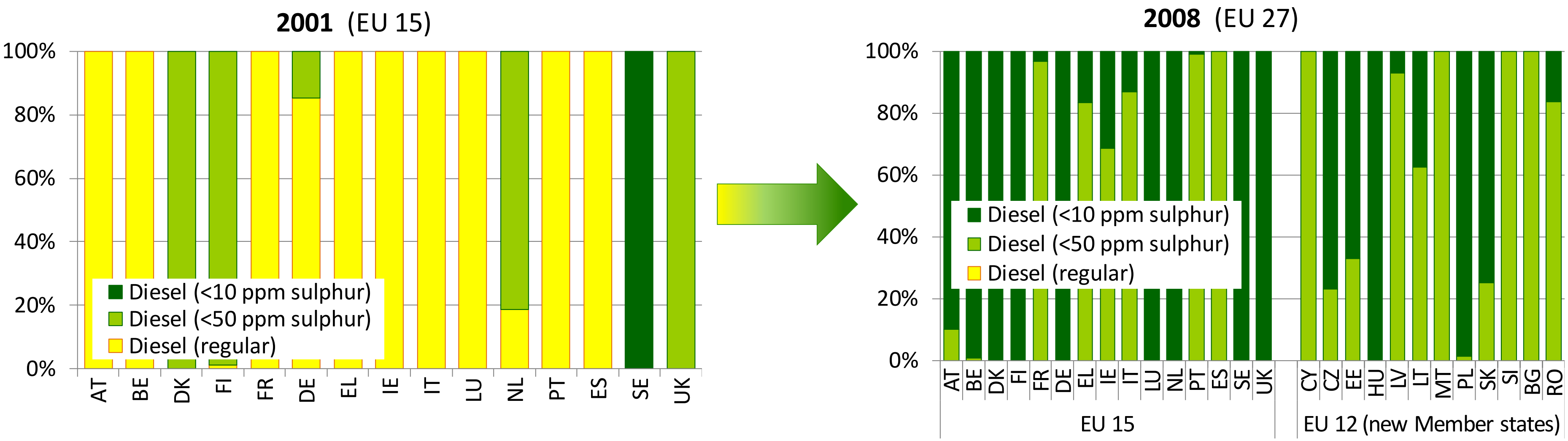
Diesel fuel in Germany is “sulphur-free” since 2003...



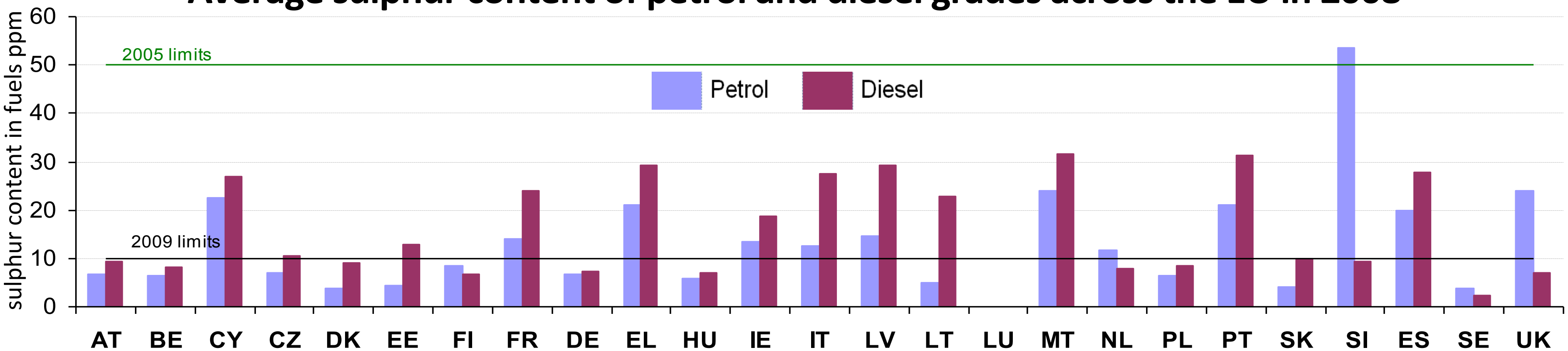
Source: IFEU/TREMOD 2011

… and Europe is on the way to "sulphur-free" diesel fuel

National sales of low sulphur diesel grades across the EU (%) in 2001 & 2008



Average sulphur content of petrol and diesel grades across the EU in 2008



Source: COM (2004, 2011) Quality of petrol and diesel fuel used for road transport in the European Union

Emissions from heavy-duty trucks I

- As a result of exhaust emission and fuel quality regulations in Europe, specific NO_x and PM emissions of trucks have improved in the last years. New heavy-duty trucks (Euro V, Euro VI) emit only a fraction of the emissions caused by older trucks.
- Although the development of real emissions from new trucks is quite similar to the decrease of limit values, new emission standards did not always bring the expected emission improvements. E.g. from Euro I to Euro II, real world NO_x emissions of heavy-duty trucks increased slightly instead of expected reductions. This underlies the importance of resilient, real-world suitable test cycles.
  Further information can be found in Dieselnet 2003: “German UBA finds increased NO_x emissions in Euro 2 trucks” http://www.dieselnet.com/news/2003/02uba.php).
- Emission measurements on heavy-duty trucks show a high impact of usage patterns on real-world emissions.
  - Vehicle use under unsteady, dynamic conditions with low speeds, e.g. in urban areas, leads to higher emissions than motorway travel at higher and mostly constant speeds.
  - This is of special concern for SCR systems that are least effective in situations with low exhaust temperature. Specific NO_x emissions of 40-ton trucks in urban operations can be more than three times higher than on motorways.
  - Hence, for reducing truck-related air pollution in cities, defining additional requirements for inner-urban emission reductions could be helpful.

Emissions from heavy-duty trucks II

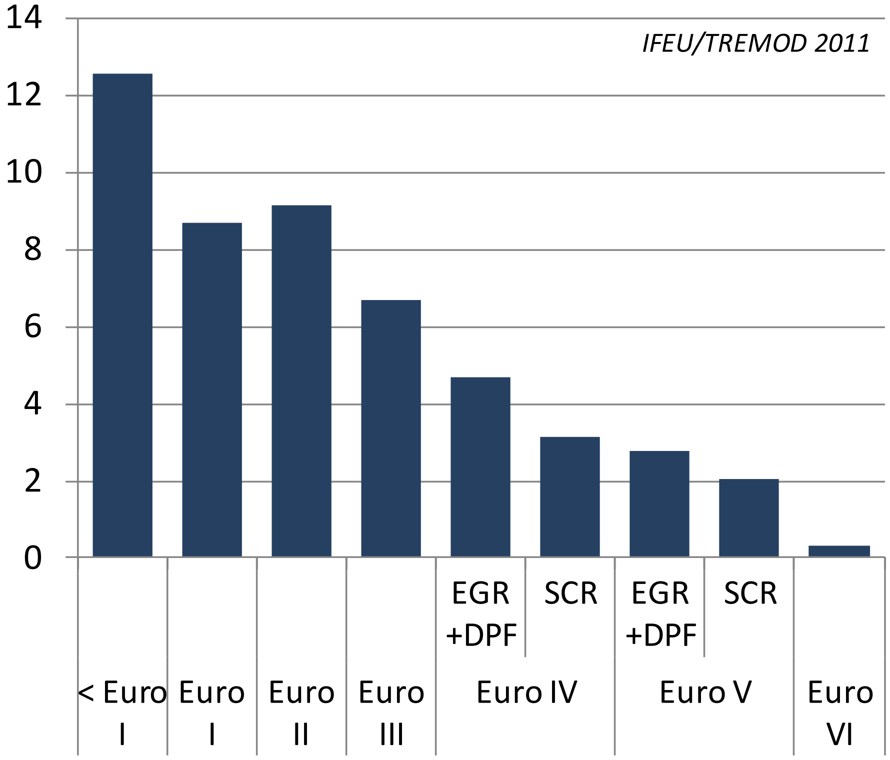
- Furthermore, the utilization of vehicle's payload affects specific emissions. Higher load factors usually increase emissions per vehicle-km due to increased pollutant levels in the engine exhaust.
  - Certainly, for NO_x from SCR-equipped trucks this correlation is not that clear. On one hand, engine-out emissions increase with the higher engine loads. On the other hand, however, the effectiveness of the downstream SCR system increases as well due to higher exhaust temperatures.

  In the end, real emissions related to the transported goods (ton-km), decrease for all emission standards with increasing load factors.

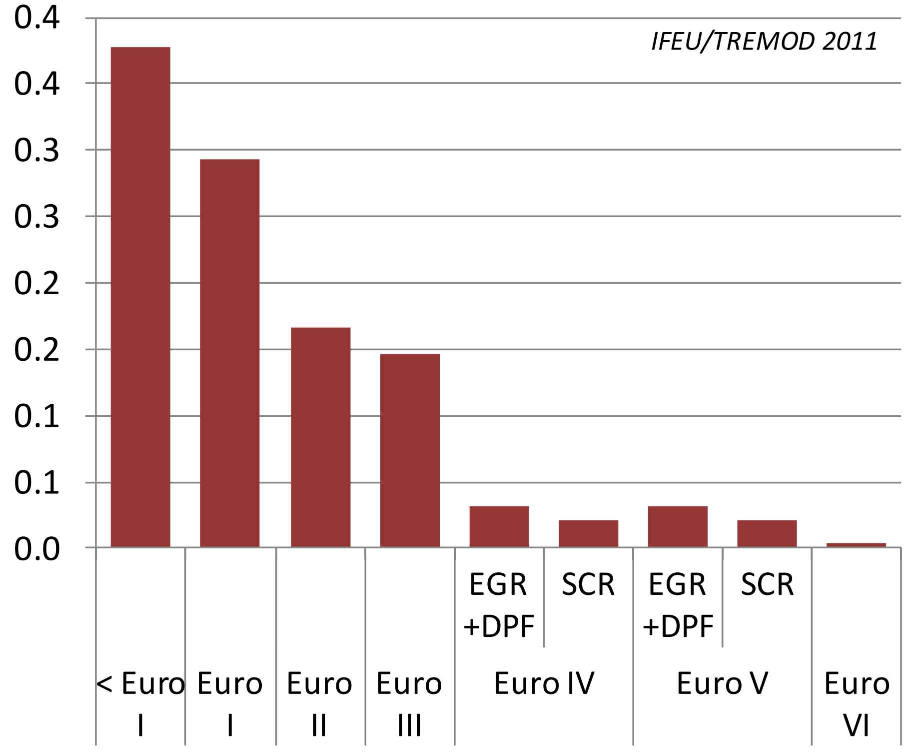
- The enhanced use of large 40-ton trailer trucks and their increasing share of road freight transport has also supported the reduction of air pollutant emissions per transported good (ton-km) in Germany. Trailer trucks with a maximum vehicle weight of 40 tons and about 26 tons of payload have considerably lower emissions per ton-km than smaller trucks with less payload.

NO_x and PM real world emissions improved significantly

Average NO_x emission factors of 40-ton trucks in g/km

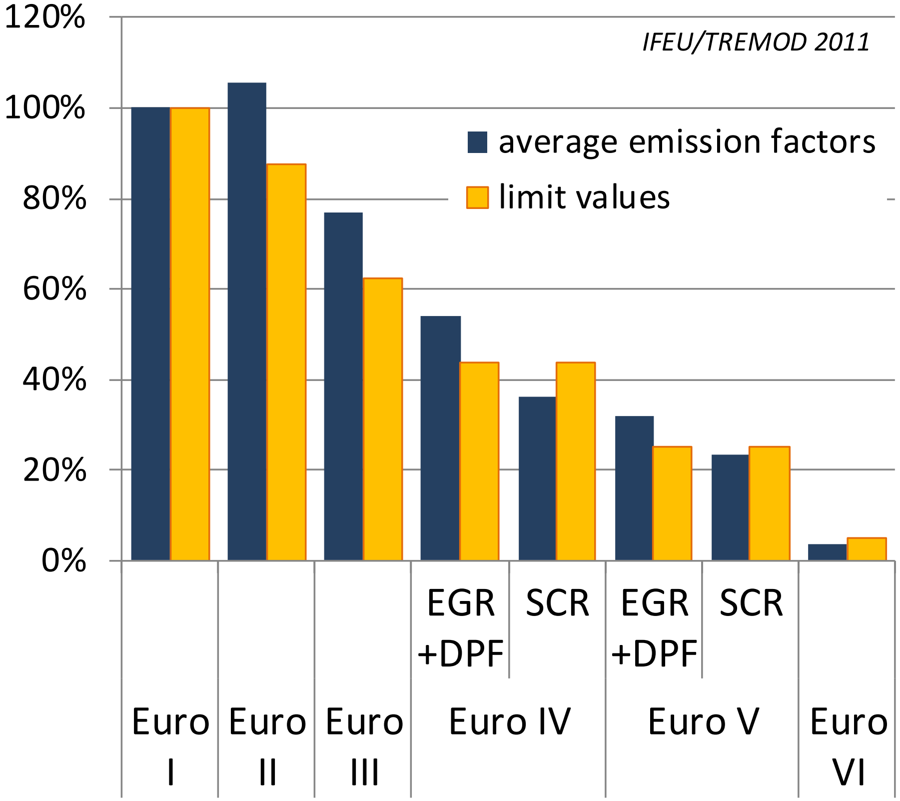


Average PM emission factors of 40-ton trucks in g/km

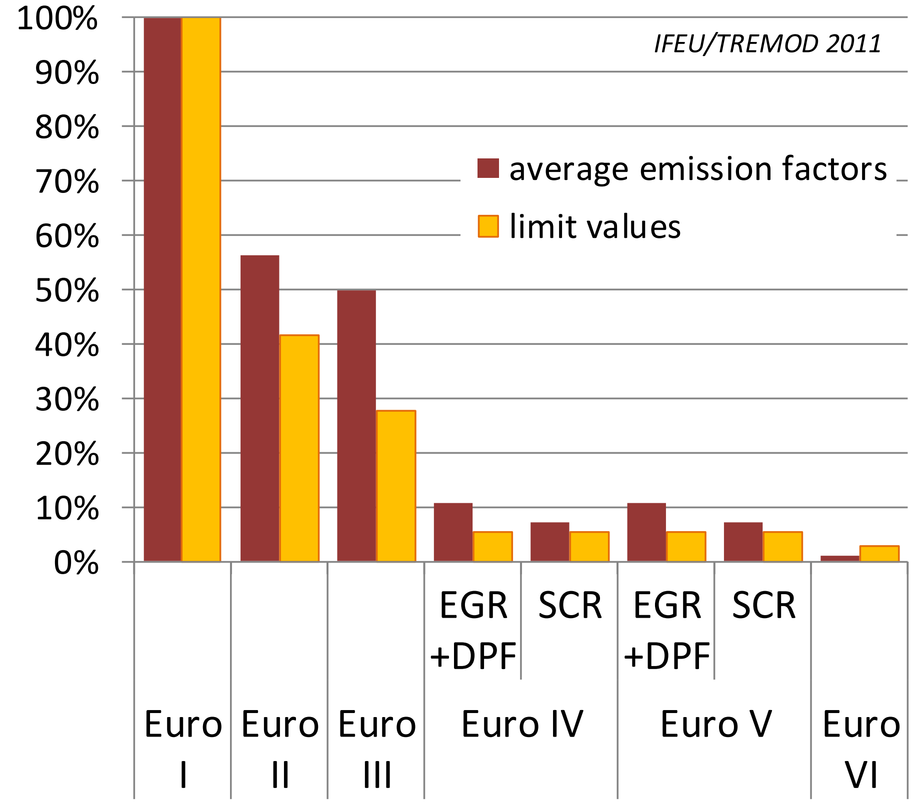


NO_x and PM real world emissions improved significantly - though decreasing more slowly than emission legislation

NO_x real emissions compared to standards

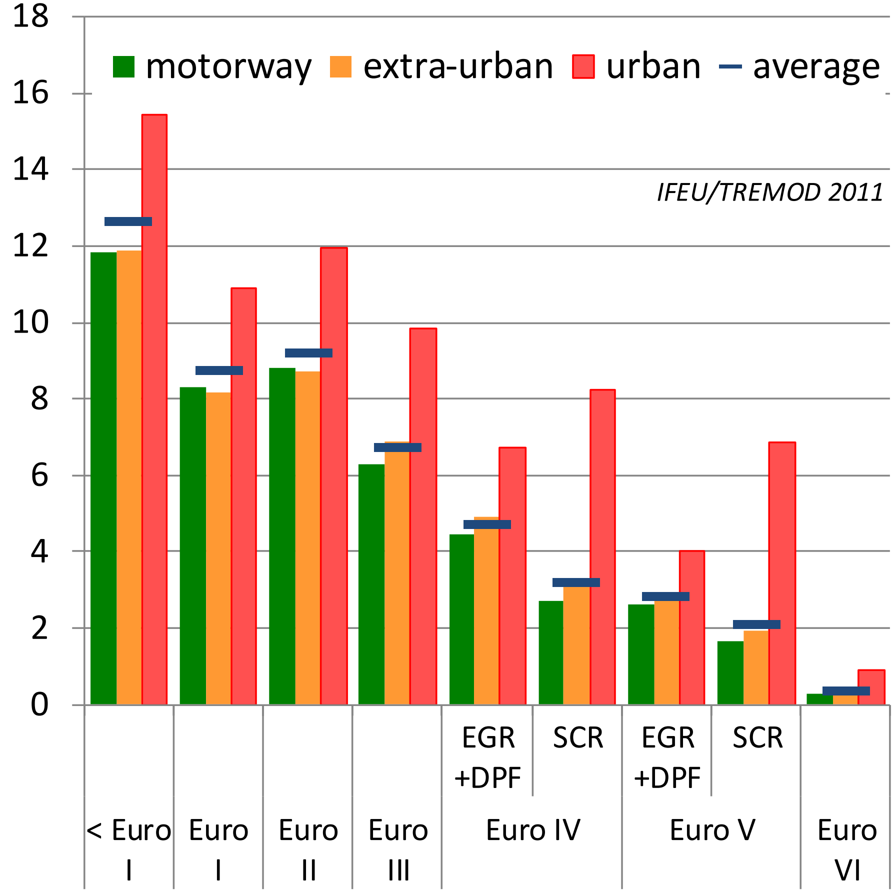


PM real emissions compared to standards

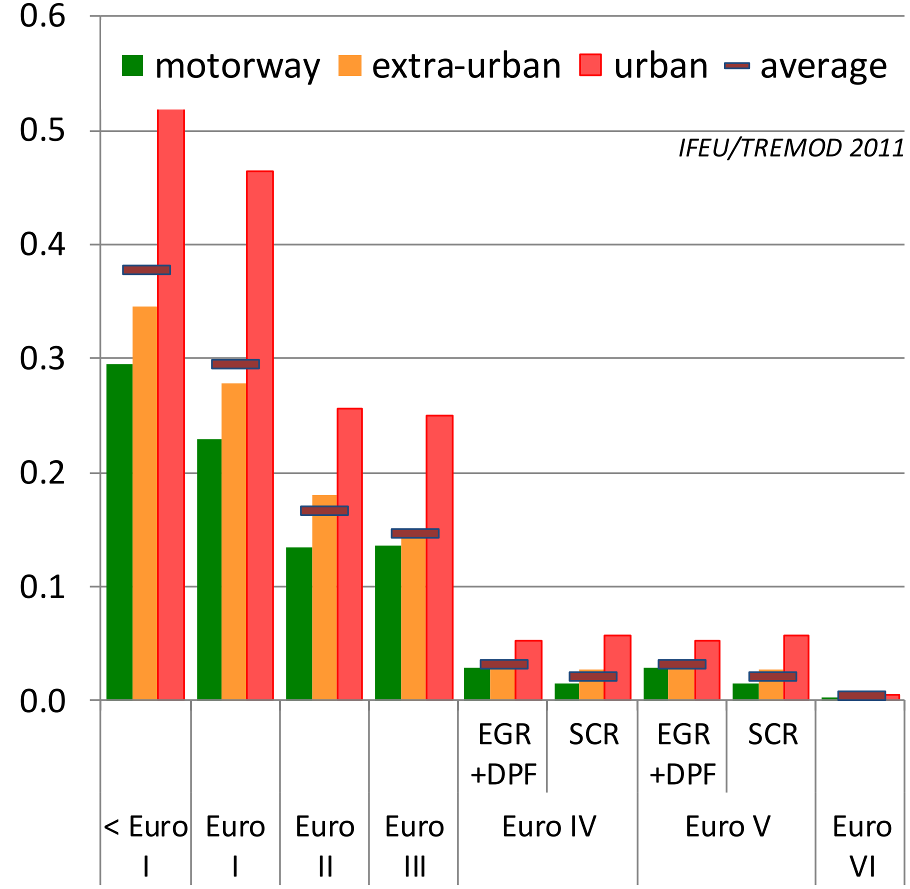


Usage patterns have high impact on emissions

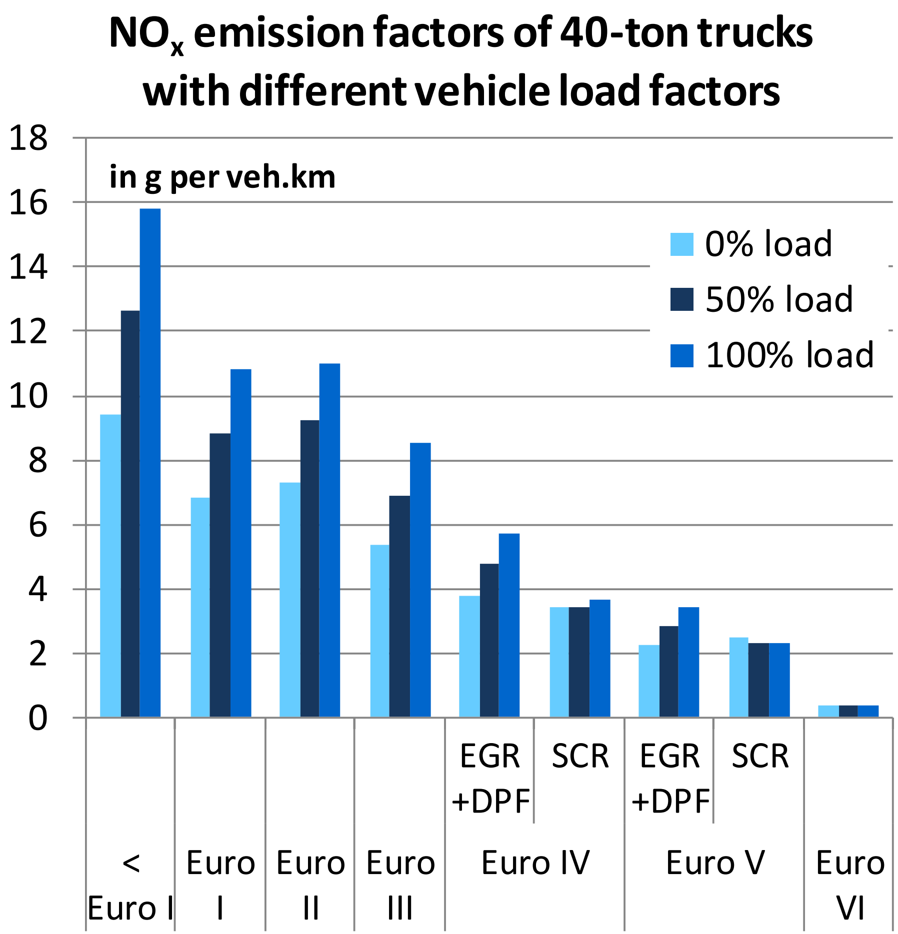
NO_x real emissions in g/km (40-ton truck)

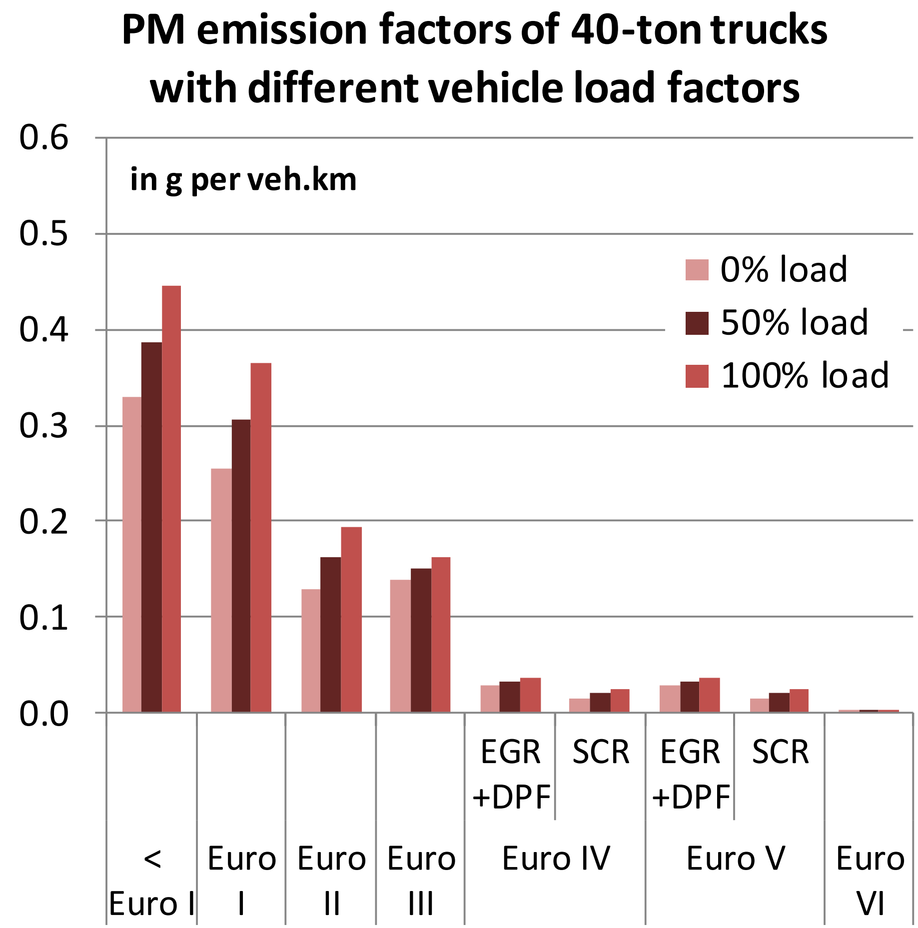


PM real emissions in g/km (40-ton truck)



NO_x and PM real-world emissions depend strongly from load

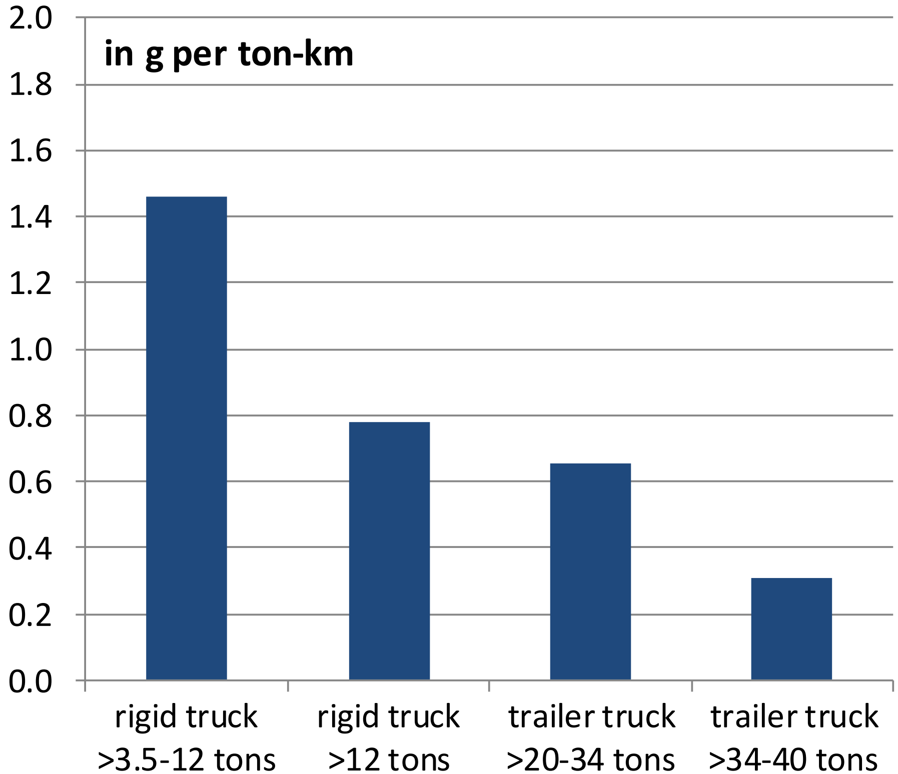




Source: HBEFA 3.1

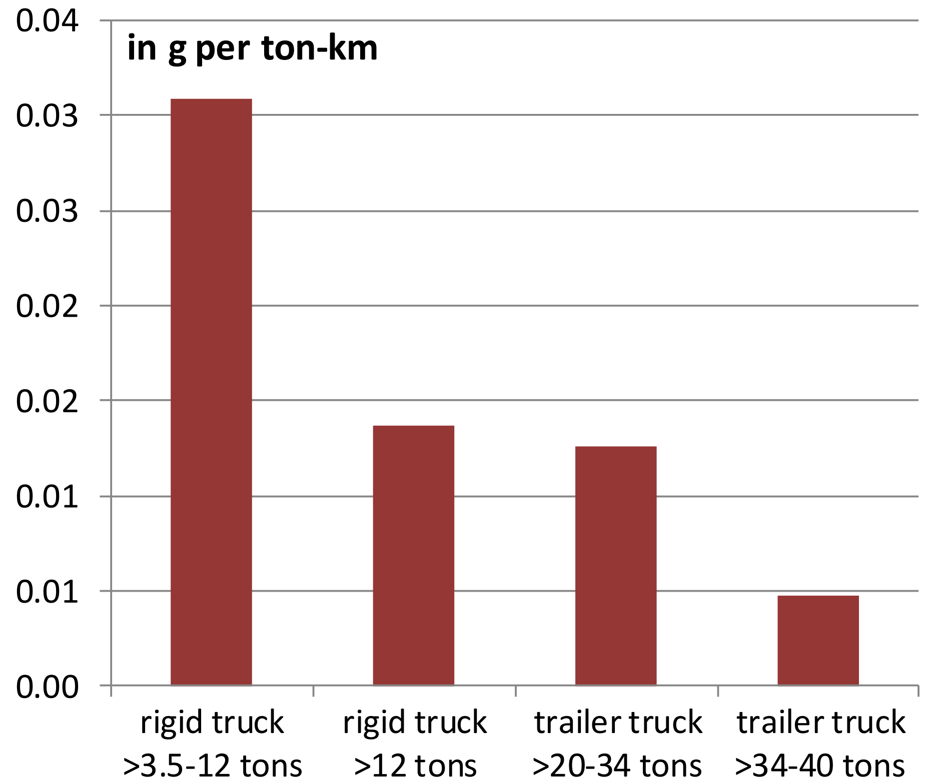
NO_x and PM emissions per ton-km decrease strongly with vehicle size

Average specific NO_x emissions in 2010 for different truck sizes per ton-km
(vehicle load: 50%)



Source: HBEFA 3.1

Average specific PM emissions in 2010 for different truck sizes per ton-km
(vehicle load: 50%)



Fuel efficiency and GHG emissions from heavy-duty trucks I

- Long-term test reports for new, fully laden long-haul trucks with a total vehicle weight of 38-40 tons show significant reductions of specific fuel consumption since the mid 1960's. However, during the last 20 years, fuel consumption of new trucks has nearly stagnated. A new 40-ton truck Euro V has about the same fuel efficiency as a Euro I truck. GHG emissions are directly related to the fuel efficiency, so specific GHG emissions per vehicle-km were not reduced.
- This absence of further efficiency improvements of new heavy-duty trucks is strongly related to the introduction and tightening of European air pollution emission standards. Up to Euro III, these were generally achieved with internal engine optimizations, hampering fuel efficiency optimization. Also the EGR+DPF for Euro IV/V causes additional fuel penalties, compensating other, fuel-saving effects. Only, the use of SCR systems allows for engine optimization to focus more on fuel efficiency.
- Similar to air pollutant emissions, fuel efficiency and GHG emissions per transported good (ton-km) improve with higher vehicle load factors. Increasing the load factor of a Euro V 40-ton trailer truck from 50% to 67% leads to an increase of fuel consumption per vehicle km by 8%. However, per transport-km, specific fuel consumption and GHG emissions decrease by 20%.
  - It should be noted that the vehicle load does not only depend on logistical optimizations of the transport chain and avoidance of empty trips, but also on the kind of good. Heavy goods such as coal or liquids lead typically to a higher utilization of the vehicle's capacity than light volume goods such as furniture, clothes etc.

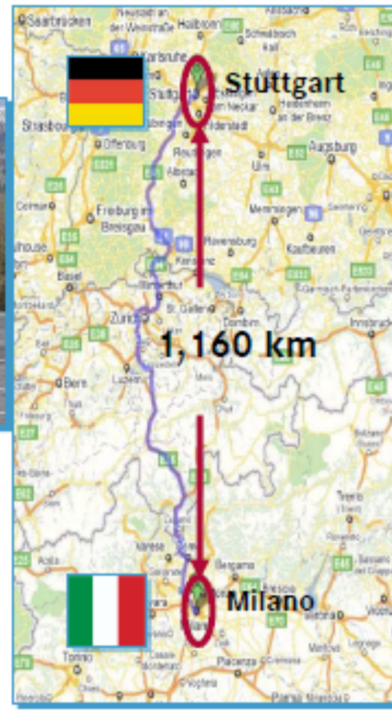
Fuel efficiency and GHG emissions from heavy-duty trucks II

- 40-ton trailer trucks need on average more than twice the fuel per vehicle-km than small heavy-duty trucks with a gross vehicle weight less than 12 tons. However, a 40-ton truck has a several times higher payload (about 24-26 tons vs. 3-5 tons). Thus, per transported ton, a large trailer truck is about 3 times more energy-efficient than a small heavy-duty truck. Therefore, meeting the increasing transport demand using primarily large 40-ton trailer trucks, has supported the improvement of fuel efficiency per transported good (ton-km) in Germany.
- The relevance of different effects for the total fuel efficiency gains of road freight transport in Germany is reflected by decomposing the individual improvements:
- In the last 15 years, technological efficiency gains yielded only improvements of fuel efficiency by about 6%. Combined with increasing vehicle loads, the efficiency gain was 20%.
- The shift to larger vehicle sizes, esp. the increased share of large 40-ton trailer trucks yielded additional efficiency gains. Thus, specific fuel consumption per transported ton with heavy-duty trucks in Germany was reduced from 1995 to 2010 in total by 27%.
- Specific GHG emissions decreased by 29%, hence, slightly more than fuel consumption This can be attributed to the usage of biofuels in Germany and additional reduction of specific GHG emissions.

Significant reduction of fuel consumption since 1965 higher payload and technological improvements

- Comparison on the Route Stuttgart – Milano and back
- Reduced Operation Time combined with higher Payload

Model Year 1965



Model Year 2009

Model Year 1965		Model Year 2009	
Driving Time:	20:08 hrs	Driving Time:	15:26 hrs
Average Speed:	58 km/h	Average Speed:	76 km/h
Payload:	16 t	Payload:	25 t

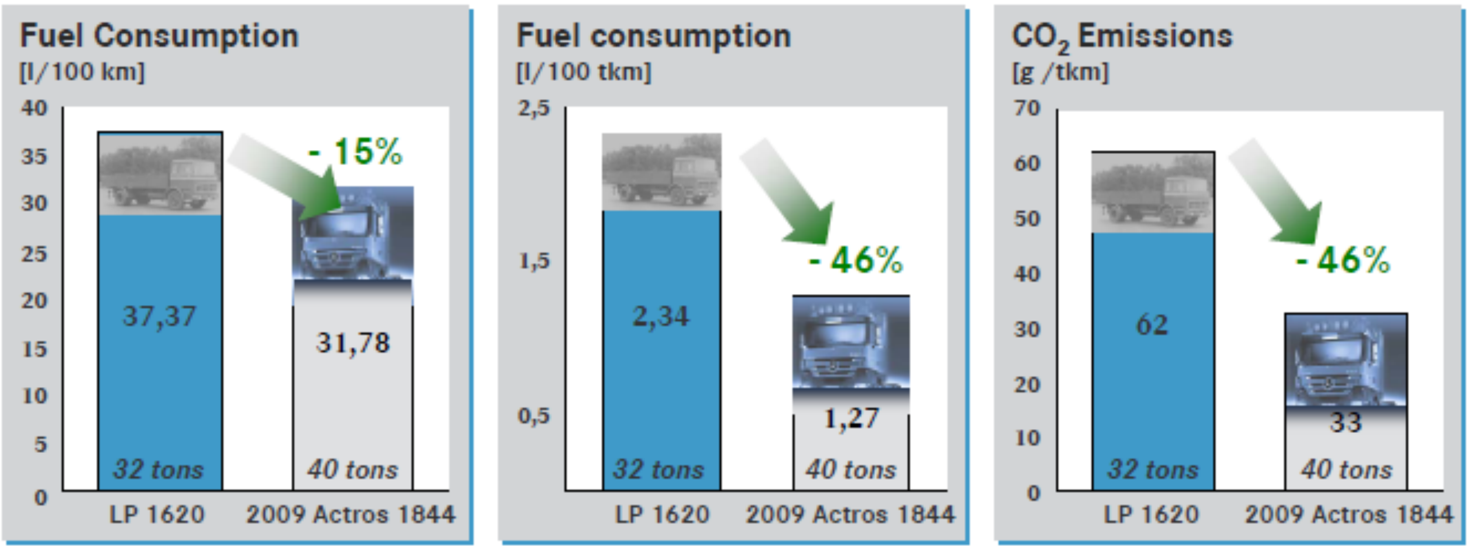
Transalp Trucking 2010 - 50 Years of Continuous Progress – Daimler AG

- Almost 25% less driving time and 64 l diesel savings on the route Stuttgart – Milano and return

Source: Manfred Schuckert, Daimler AG, presented by Daimler on EC/ICCT-Workshop , November 2011

…fuel consumption per ton km almost halved by technology improvements and higher loads

- Higher payload together with less fuel consumption and CO_2-emissions per ton and kilometer*.



Transalp Trucking 2010 - 50 Years of Continuous Progress

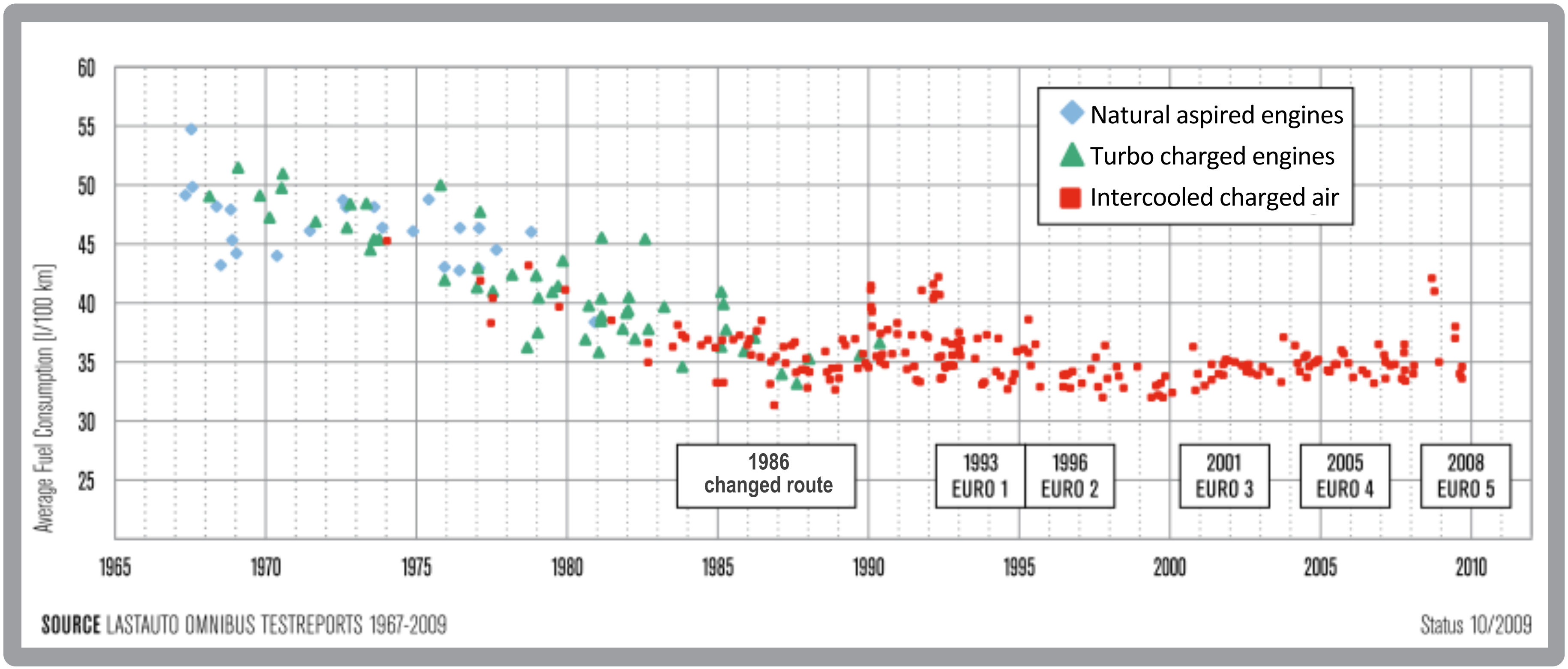
* measured on 1,159.6 km Transalp Test Drive

- **Fuel consumption and CO2 emissions per tkm almost halved.**

Source: Manfred Schuckert, Daimler AG, presented by Daimler on EC/ICCT-Workshop , November 2011

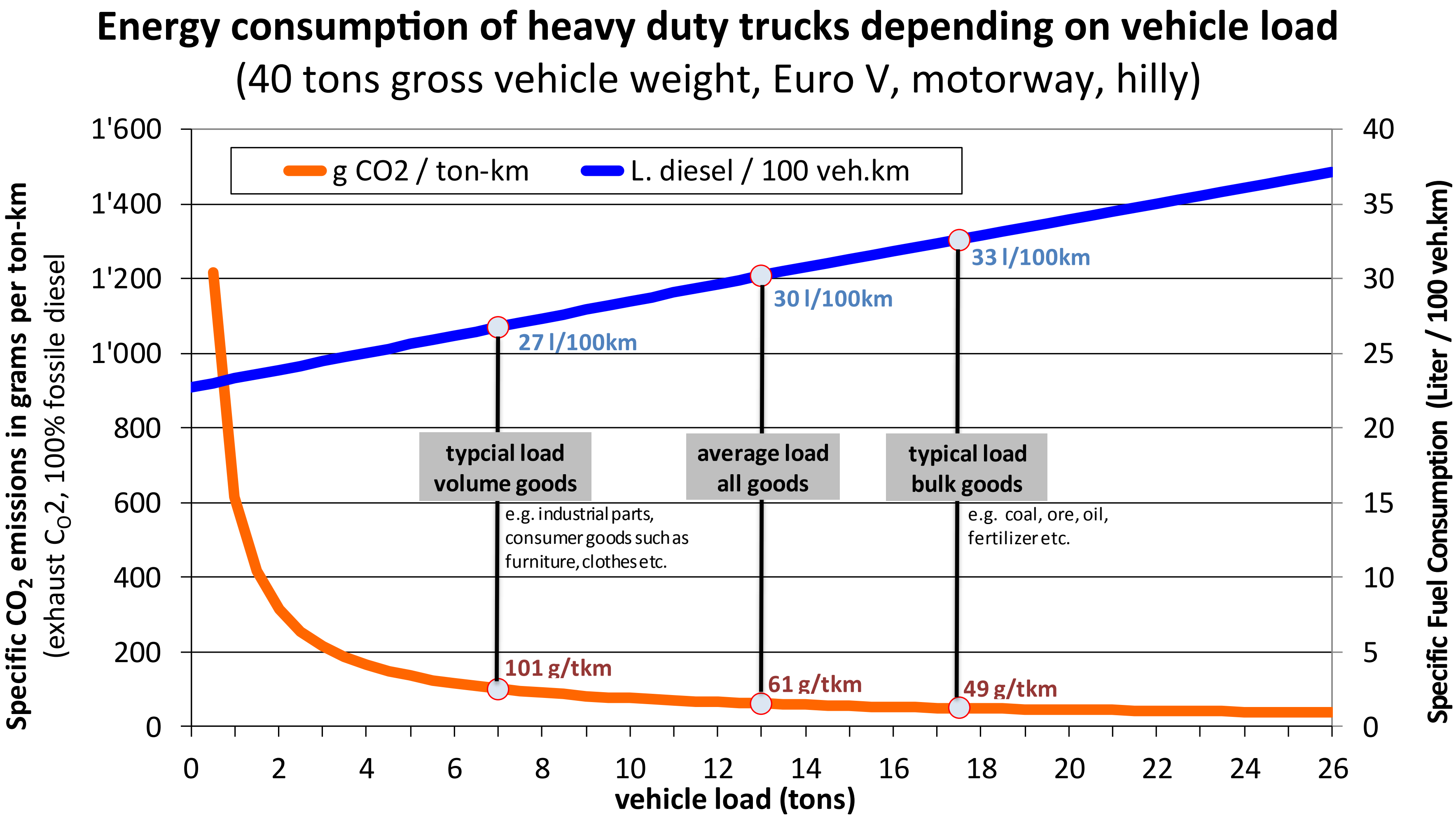
Significant reduction of specific fuel consumption before 1990; nearly stagnation the last 20 years

Fuel consumption of long-haul trucks (GVW 38/40 tons) in long-term test reports



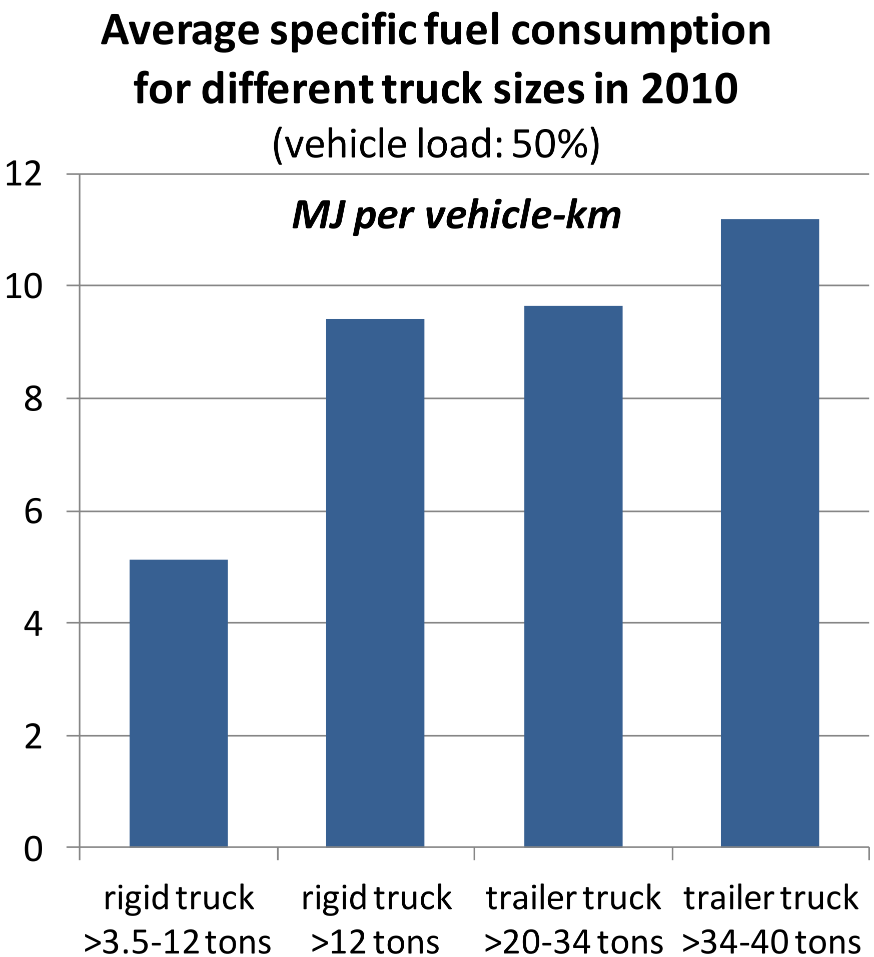
Source: ACEA 2011 Commercial vehicles and CO_2

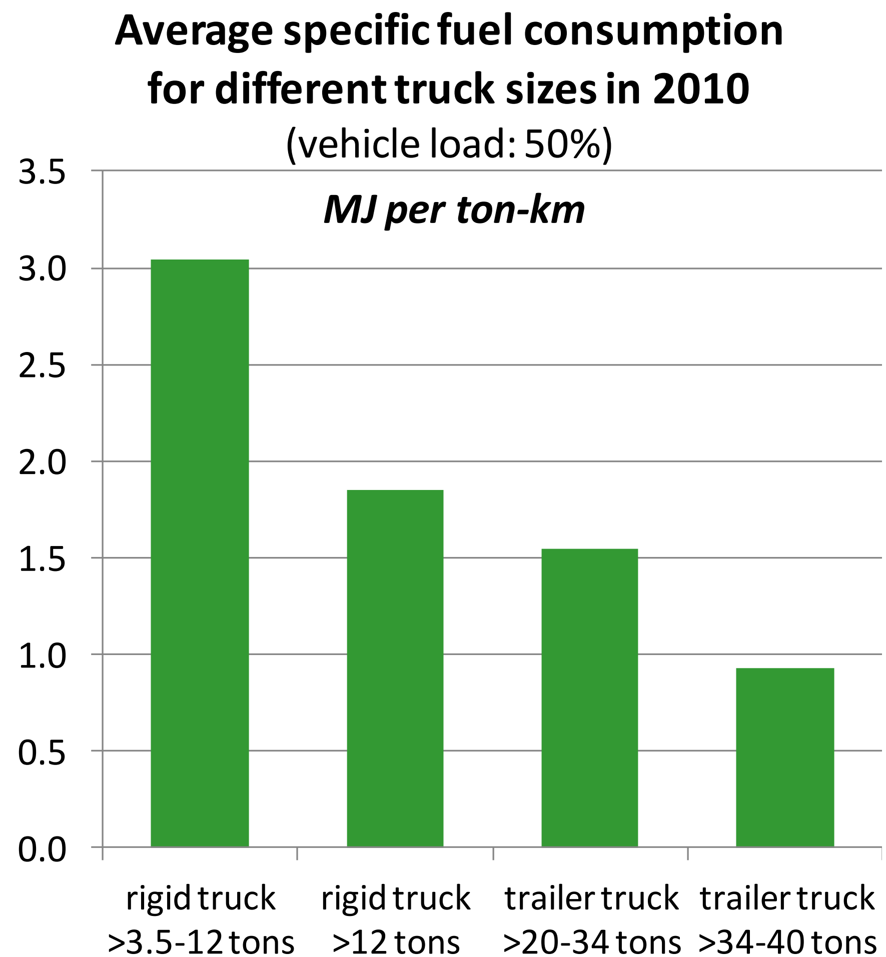
Higher loads lower strongly the specific fuel consumption



Source: HBEFA 3.1, EcoTransIT (www.EcoTransIT.org)

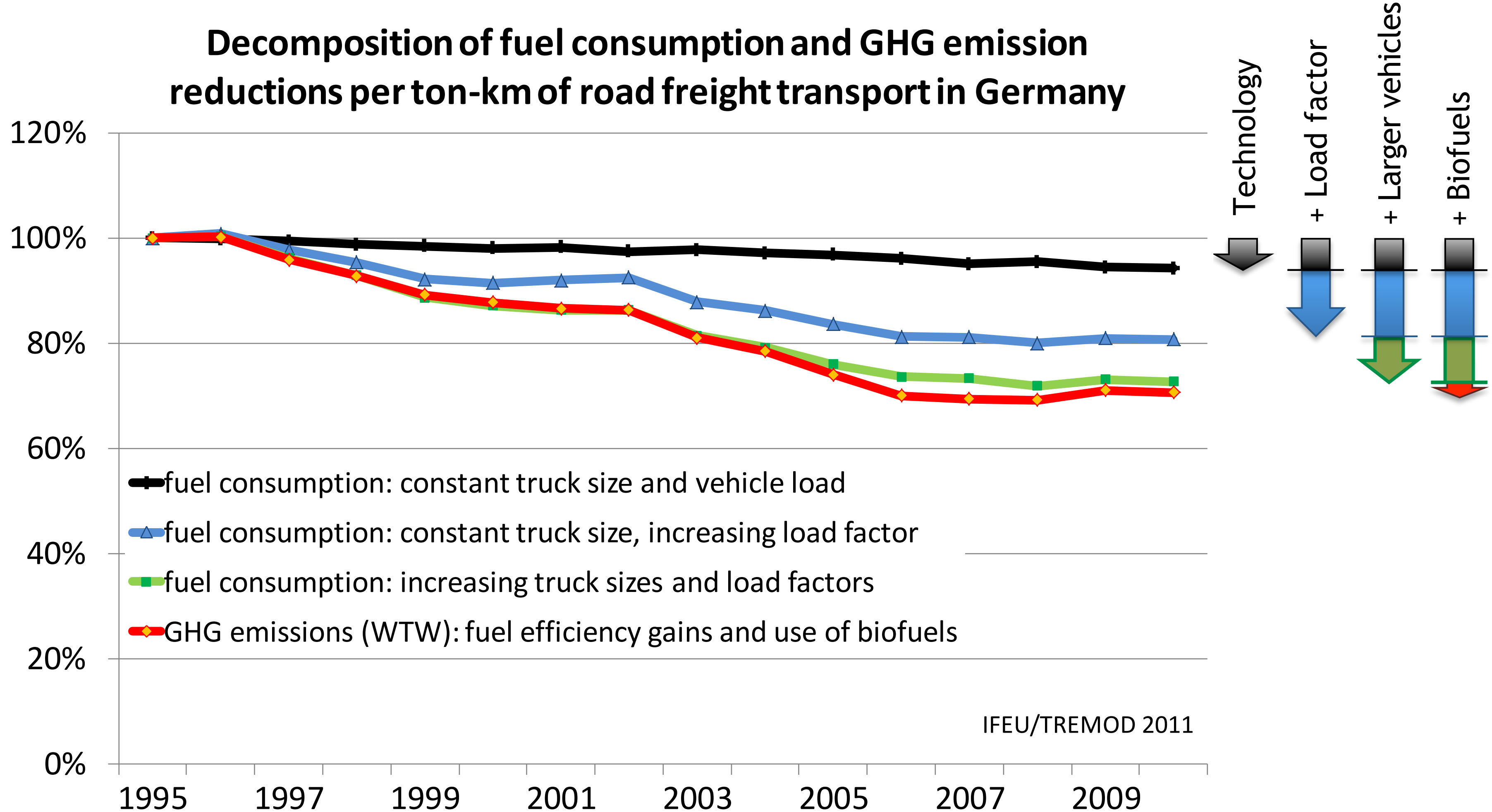
...fuel consumption increases with vehicle size, but specific energy consumption (per ton-km) decreases





Source: HBEFA 3.1

Specific energy consumption of freight transport with heavy-duty trucks reduced by 30% in the last 15 years

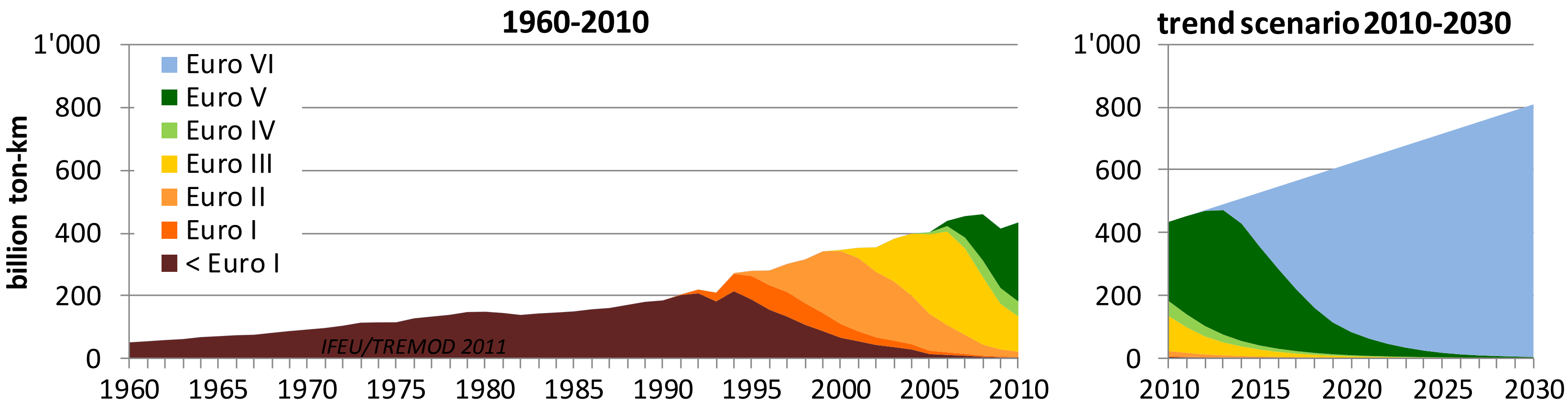


Development of transport, emissions and fuel efficiency

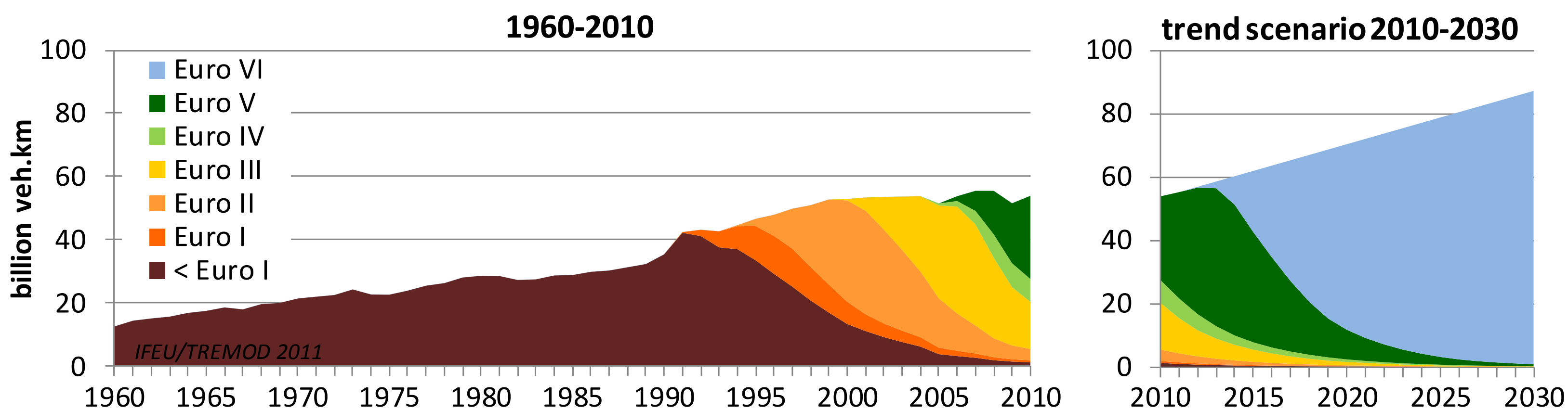
- Comparisons of past developments and future projections show the importance and the success of air pollutant emission regulations in Europe. They also demonstrate the limited success of efforts to reduce fuel consumption and GHG emissions from road-freight transport.
- Transport performance and mileage of heavy-duty trucks increased strongly from 1960 to 2010. In the first decades, emissions of NO_x and PM increased to a similar extent. However, with the introduction of European emission standards, emissions could be strongly reduced. Compared to 1995, transport performance increased by 55% and mileage by 16%. In contrast, NO_x emissions were reduced by 55% and PM emissions by 76%.
- By 2030, further considerable increases of road freight transport performance (+189% compared to 1995) and mileage (+87%) are expected in current transport projections for Germany. In the same time frame, air pollutant emissions are expected to decrease by 93% (for NO_x) and 98% (for PM).
- The development of fuel consumption and GHG emissions cannot show similar success' as air pollutants. From 1995 to 2010, fuel consumption (+13%) and GHG emissions (+10%) increased only slightly lower than mileage of heavy-duty trucks. Also for 2010 to 2030, no clear decoupling of fuel consumption and GHG emissions from transport development can be seen. In case of the currently projected transport development, GHG emissions of road freight transport will continue to increase as the high transport increase overcompensates for future expected efficiency gains.

Projections show further increase of transport performance and mileage of heavy-duty trucks in Germany

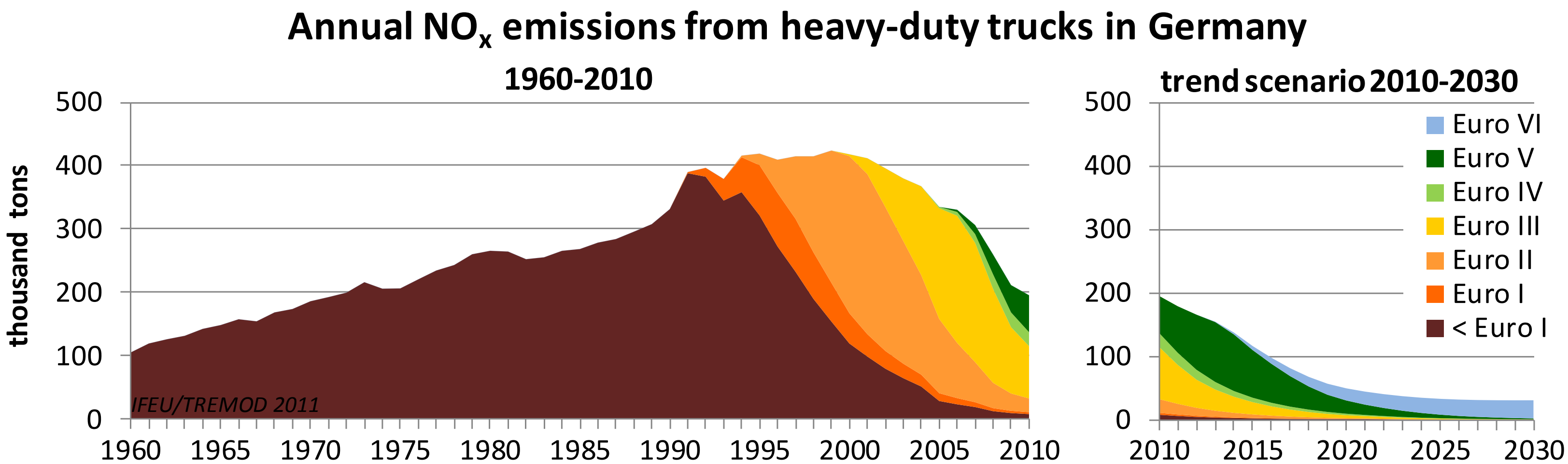
Transport performance of heavy-duty trucks in Germany

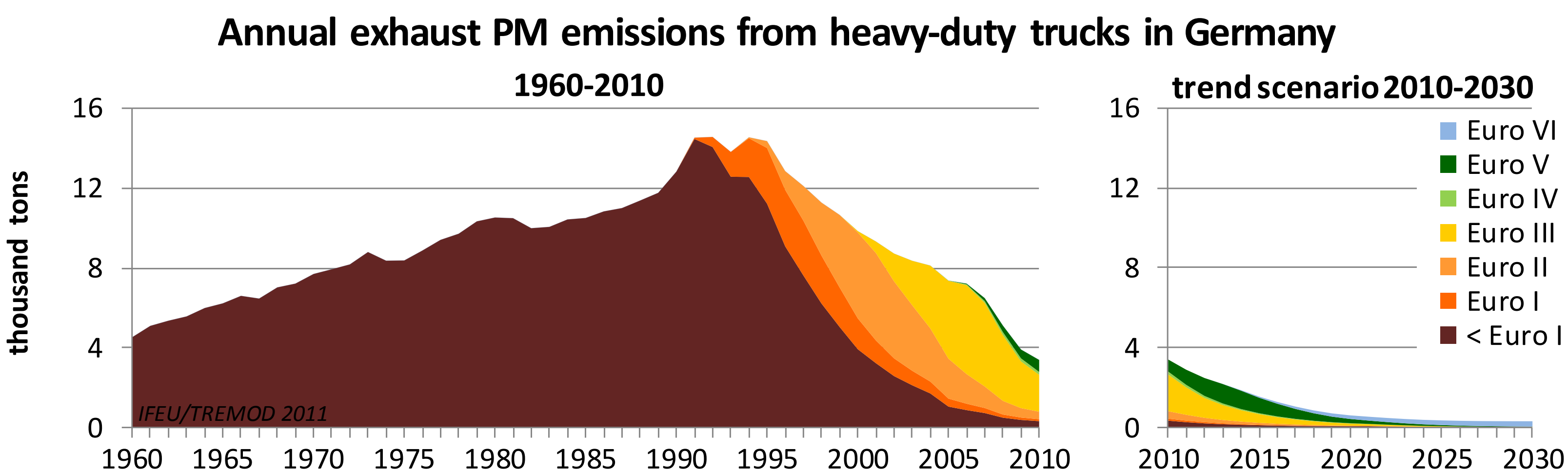


Annual mileages of heavy-duty trucks in Germany



Despite of increasing goods transport NO_x and PM emissions from heavy-duty trucks will decrease





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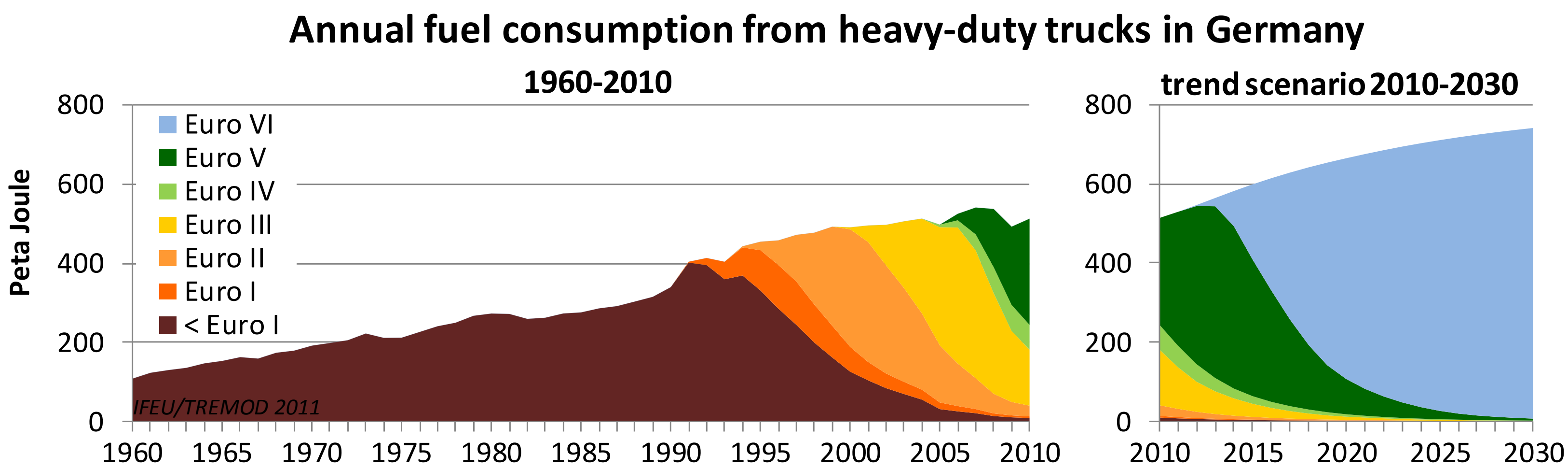
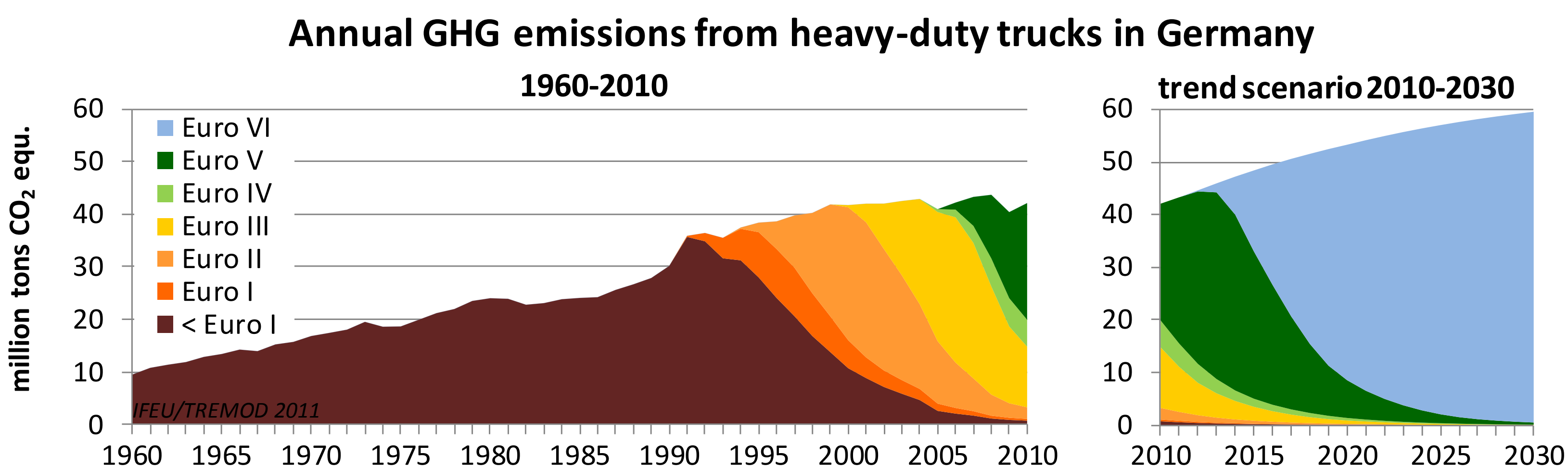
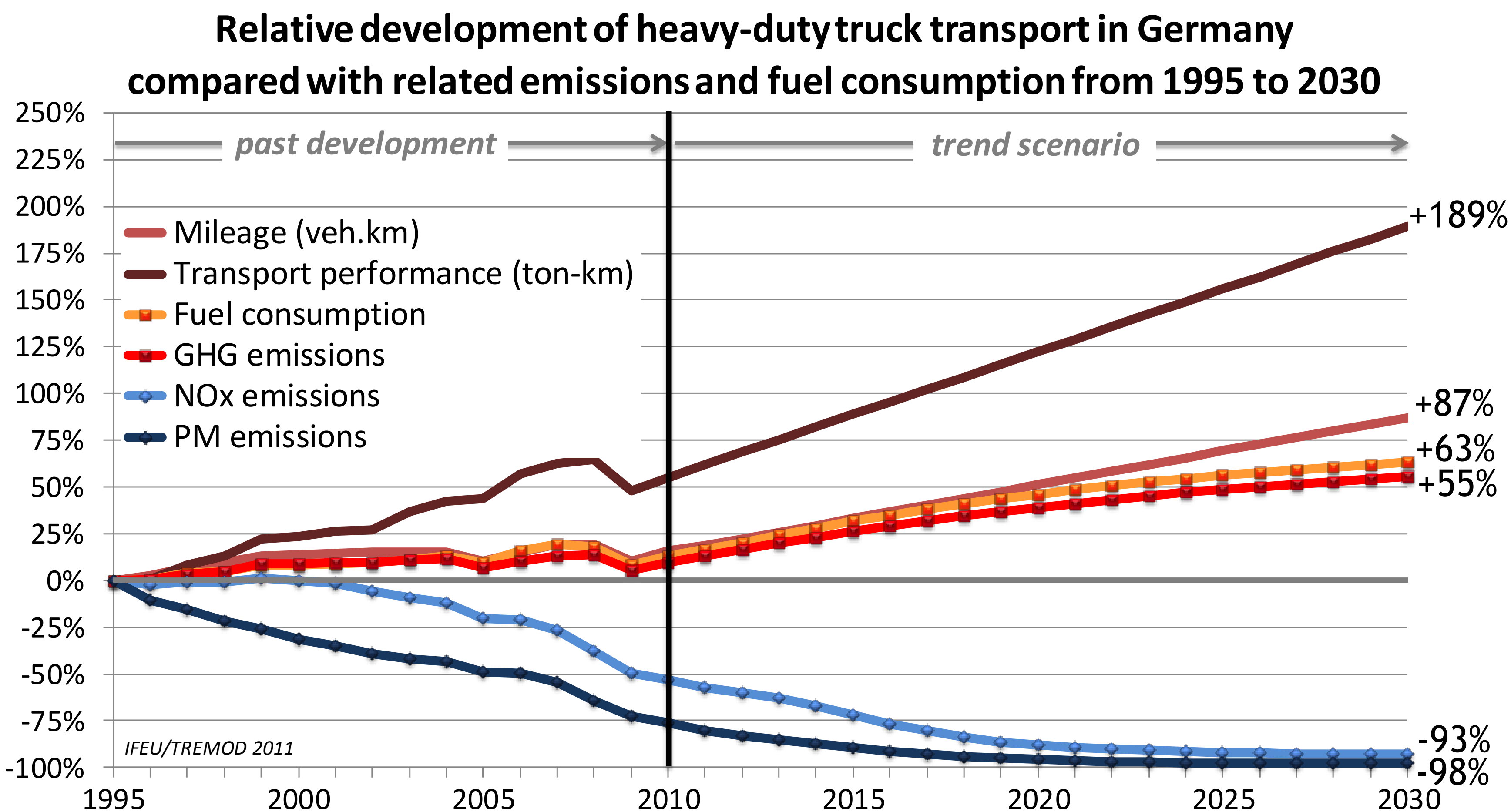
...but increase of fuel consumption and GHG since efficiency gains are overcompensated by high increase of transport





Strong decoupling of air pollutant emissions from transport development. For GHG emissions only lower effects expected



Summary

- High increase of truck transport led to increasing share on fuel consumption and GHG emissions – and significant contribution to NO_x and PM emissions.
- In the last 20 years, NO_x and PM exhaust emissions from heavy-duty trucks improved significantly as a result of EU fuel quality and emission legislation
- Usage patterns, vehicle size and load still have high impact on exhaust emissions per vehicle km and ton-km.
- Specific fuel consumption of new trucks decreased significantly before 1990, however, nearly stagnation in the last 20 years.
- Higher vehicle loads and shift to larger vehicles considerably reduced the specific fuel consumption and GHG emissions per transport volume.
- For the future, projections show further increase of transport volumes and mileage of heavy-duty trucks in Germany.
- Even so, NO_x and PM emissions from heavy duty trucks will decrease.
- However, fuel consumption and GHG emissions will continue to increase as the high transport increase overcompensates expected efficiency gains.

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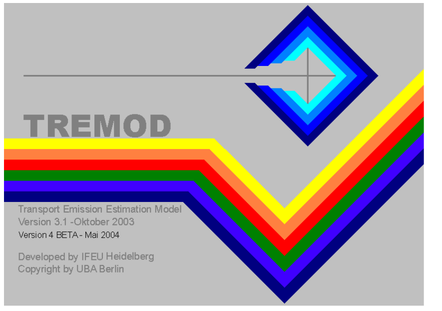
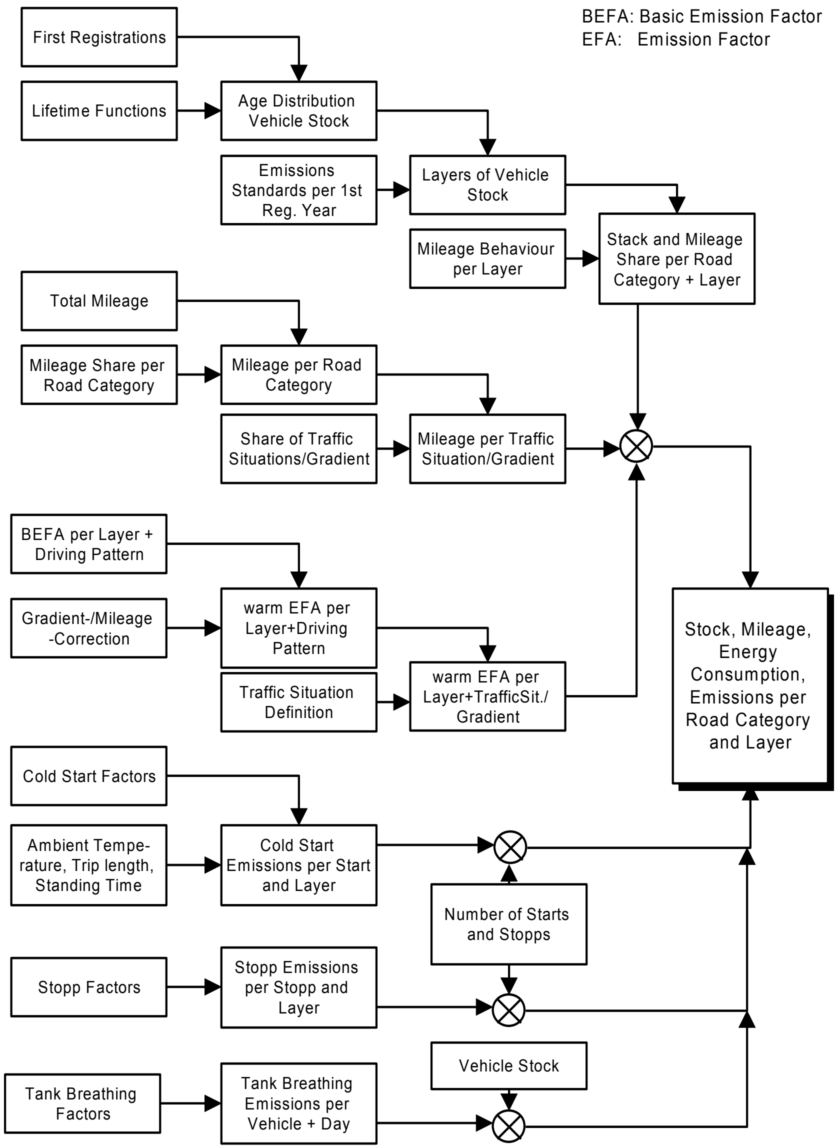
- **TREMOD: TRansport Emission MODel**
  - Developed by IFEU for and in close cooperation with the German Federal Environment Agency, Ministry of Transport, Association of Automobile Manufacturers and others (since 1993)
  - Official database for emission reporting of the German Government



- **Based on a range of European measurement programs:**
  - **Measurement of the driving patterns of vehicles**
    - Cycles recorded in real world traffic (car following method)
    - Weighted by traffic volume for a specific traffic situation
  - **Measurement at vehicles (emission behaviour)**
    - Vehicles grouped to different layers with comparable emission characteristics (vehicle types and sizes/ EURO stages, etc.)
    - Engine maps/ Real world cycles
    - Weighting according to fleet composition
  - **Harmonized with "Handbook of Emission Factors" (INFRAS Bern et al.)**
  - **ERMES Group: European Research Group on Mobile Emission Sources**



Modelling all relevant factors:

- driving behaviour,
- mileage,
- load factor,
- differentiated emission factors,..

Estimation of

- fuel consumption and
- exhaust and evaporative emissions (CO_2, CO, NO_x, NMHC, CH_4, benzene, SO_2, particulates, N_2O, NH_3).
- for all motorized passenger and goods vehicles.
- for Germany year by year from 1950 to 2030
- for various scenarios.