The Efficiencies of Combined Transport

a study into the energy-, labour-, infrastructure-, safety and environmental/climate efficiency of door-to-door combined transport, and its potential impact on Europe's land transport system

---prepared for UIRR, the International Union for Road-Rail Combined Transport

ABE CONSULT

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Management Summary

Combined transport: an across-the-board competitiveness-booster of freight transportation

The study has found that the superior properties of rail freight or waterborne transport when employed through combined transport and in comparison to contemporary trucking, even after corrections for the needed intermodal transhipments, enable the delivery **of significant gains in energy efficiency, infrastructure mainenance cost savings, labour productivity, accident prevention, environmental improvements and congestion reduction**.

Through the use of intermodal transhipment techniques, combined transport **efficiently inserts modes of transport such as electric rail freight and waterborne means into transport-chains of truckloads of any type of cargo** that are otherwise carried by unimodal trucking.

In this study an evidence-based evaluation of a wide range of measures proposed to enhance the efficiency performance of transportation of goods by heavy goods vehicles has been caried out. These measures range from improved aerodynamics, slower speeds, longer and heavier vehicles (a.k.a. the European Modular System, or EMS, trucks), alternative fuels (including hydrogen-powered propulsion systems), through road infrastructure design, maintenance and reinforcement upgrades, to active and passive means of labour productivity and safety improvements. The evaluation shows that the **marginal cost of these improvements are very high, especially in comparison with the modest gains to be achieved**, and when comparing to what contemporary combined transport operations can instantly deliver without any spending needs.

The shifting of longer distance transport-chains from unimodal trucking to combined transport can **deliver tangible savings to public budgets as well as to economic operators**. Savings which materially contribute to the overall competitiveness of European supply chains and the economy at large. The identified efficiency advantages translate into immediate savings counted in the many dozens of billions of euros annually. **The positive impacts accelerate with time** eventually resulting in further boosts to economic competitiveness, reduced expenses for public budgets, improved public health and greater prosperity.

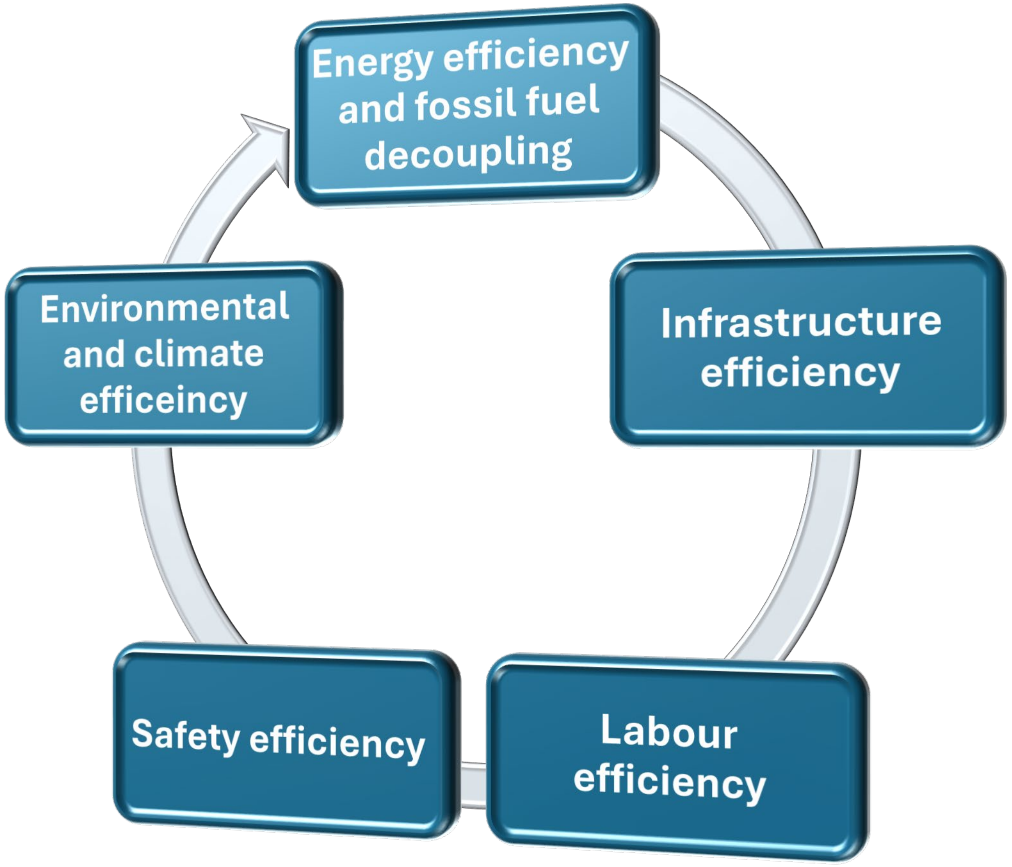
More combined transport frees up limited resources that can be redirected to other aspects of the economy generating further competitiveness gains. This constitutes a valuable **secondary wave of efficiency improvements** that can materially contribute to the long-term competitiveness of the European economy.

The **policy objectives of the European Union** concerning air pollution, the number of road accidents and accident fatalities, as well as greenhouse gas emissions could be met if an accelerated shift from unimodal trucking to combined transport was to occur, **member states would realise substantial savings** in infrastructure development and maintenance, as well as a reduction in accident-related social security expenses, while **economic actors would enjoy** superior labour productivity rates and the positive results of reduced road congestion: **a win-win for all**.

Management Summary: the results in numbers

Combined transport – compared to unimodal truck transport – can deliver meaningful results in every examined dimension:

- **70%** better energy efficiency
- **Up to 50%** road infrastructure maintenance expense saving
- **60%** better labour productivity and improved work/life balance
- **95%** fewer accidents per tonne-kilometres
- **Up to 84%** fewer air pollutant and greenhoue gas emissions
- **50%** reduction of road congestion related to maintenance works and accidents



Management Summary: combined transport's capabilities in monetary terms

How much is combined transport's contribution potentially worth in monetary terms if combined transport were to become the backbone of longer distance land freight transport in Europe?

- 70% better energy efficiency = **€0,3 energy saving per long distance vehicle kilometre, or €70 billion annually**
- Up to 50% road infrastructure maintenance expense reduction = **up to €20 billion savings annually**
- 60% better labour productivity and improved work/life balance = **€47 billion could be saved annually**
- 95% fewer accidents per tonne-kilometres = **up to €70 billion of savings**
- Up to 84% fewer air pollutant and greenhoue gas emissions = **up to €17 billion of savings**
- 50% estimated reduction of road congestion related to maitenance works and accidents = **€90 billion of savings**

SUMMARY: if combined transport were to become the backbone of longer distance European freight transport by 2050 which should include a saving of €47 billion (=2,5 billion man-hours of labour equal to 1,3 million full-time workers) the annual contribution to the public budgets as well as to European economic actors would amount to €314 billion, which is €222 billion net of internalisation charges paid through taxes and charges.

Scope of the Study and General Approach

Political programme of the European Union based on:

1. Florence School paper on EU Mobility and Connectivity
2. The Letta Report
3. Policy Guidelines of Ursula von der Leyen
4. The Draghi Report
5. Mission letters to the commissioners for transport, energy and the environment/climate

Efficiencies of door-to-door combined transport when measured in 5 categories:

1. Energy efficiency
2. Infrastructure efficiency
3. Labour efficiency
4. Safety efficiency
5. Environmental- and climate efficiency

The study examines the present day performance of door-to-door combined transport and places its performance in the context of the unimodal end-to-end trucking alternative when performed using a Euro 6 diesel fuelled truck.

The study also analyses the future outlook for these two modes of transport taking into consideration the foreseeable technological and organisation evolution of each.

Scope and methodology for assessing the efficiencies of combined transport

- 10 representative door-to-door combined transport relations used for the energy-, labour- and environmental/climate efficiency dimensions.
- Actual employment data was collected from practicing UIRR members through a targeted questionnaire and deep interviews, which was complemented by desktop research.
- The technology potential for shorter-distance and longer-distance heavy duty trucking, as well as rail freight transport and intermodal transhipment techniques has been assessed through means of desktop research.
- Besides offering an in-kind evaluation for both present day best practice and the future outlook for each efficiency dimension, an economic analysis has also been executed based on reference values contained in the relevant official publications of the European Commission on energy, infrastructure spending, safety, labour and environment/climate, as well as the congestion effects caused by excessive road haulage.

Modelling principles for energy efficiency and emissions (environment)

Scope

Ten representative relations

Throughout Europe

Intermodal Loading Units used

Transport in every type of intermodal loading unit (swap body, container, and semi-trailer)

Combined Transport vs. Trucking

Benchmarking of a *combined transport operation* to its equivalent unimodal trucking alternative

Approach

Two load Scenarios

Heavy Weight Scenario

Good practice ILUs and wagons, maximum permissible laden weight

Statistical Scenario

Statistical distribution of ILUs, load factors, and empty trips

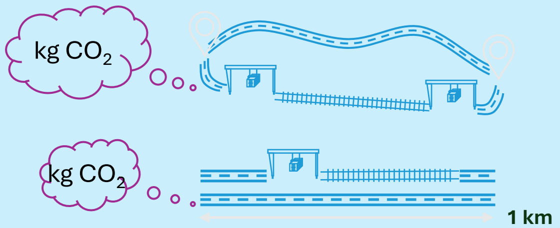
Calculations

EcoTransIT calculator

CE Delft Transport Externality Handbook

Comparability

emissions per tonne and tonne-kilometre



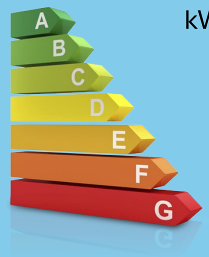
Energy use and Emissions (environment)

Bottom-up

harmful emissions based on energy consumption

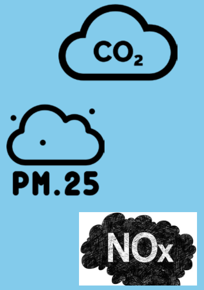
Energy provision (well-to-tank, WTT) + **Vehicle efficiency** (tank-to-wheel, TTW)

= **Well-to-Wheel** (WTW)



Energy-efficiency

kW per tonne-kilometre



Harmful emissions

CO_2 : **climate**

PM 2.5 and PM10 : **air quality**

Nox : **climate and air quality**

Modelling principles for infrastructure, labour, safety and congestion

Infrastructure

Impact of heavy axles on the road infrastructure

Additionally looked at the case of overloaded trucks

How does axle load affect the rail infrastructure

Design bearing is 22,5t axle load

Road vs. railway maintenance

Comparison of causes of wear and tear and the costs of maintenance

Labour

Ten representative relations

Throughout Europe

Net workhour calculation based on each phase

Using industry best practice average speed and terminal transhipment times

Overhead hours per direct labour hours

Based on standard overhead benchmarks

Safety / accidents and Congestion

Ten representative relations

Throughout Europe

Basis of the evaluation

CE Delft Transport Externality Handbook

Congestion

As a factor of both infrastructure maintenance works and safety incidents (accidents)

The ten representative relations used during the modelling

	1 Vienna – Melzo	2 Malmö - Duisburg	3 Rotterdam - Vienna	4 Cologne – Busto	5 Munich – Verona	6 Hamburg - Budapest	7 Valenton - Miramas	8 Dourges – Lyon	9 Ludwigsh. - Barcelona	10 Venlo – Poznan
Locational Properties										
Start latitude	48,14	56,68	51,95	51,01	48,18	53,51	48,91	50,66	49,44	51,44
Start longitude	16,49	16,28	4,15	6,98	11,56	9,98	2,33	3,00	7,69	5,71
Terminal 1	Vienna South Cargo Center	Malmö KT	Rotterdam RSC	Köln Eiffeltor	München Riem	Hamburg Burchardkai	Valenton	Delta 3 Dourges	Ludwigs-hafen Contargo	Cabooter rail terminal Kaldenkirchen
Terminal 2	Melzo (RCO)	Samskip Terminal Duisburg	WienCont	Busto Arsizio-Gallarate	Verona Interterminal	Budapest Metrans	Miramas	Lyon-St. Priest	Barcelona Morrot	CLIP Container Terminal Swarzędz
Destination latitude	45,50	51,38	48,18	45,64	45,42	47,42	43,61	45,69	41,37	52,40
Destination longitude	9,41	6,68	16,47	8,84	10,92	19,05	4,99	4,91	2,17	17,12
Distances										
Unimodal trucking	856 km	1166 km	1197 km	832 km	403 km	1241 km	772 km	684 km	1226 km	865 km
CT road leg 1	13 km	278 km	29 km	19 km	14 km	5 km	22 km	33 km	70 km	45 km
CT road leg 2	34 km	27 km	7 km	38 km	2 km	92 km	54 km	25 km	8 km	7 km
CT rail leg	823 km	922 km	1180 km	838 km	441 km	1208 km	709 km	631 km	1342 km	847 km

1. Energy efficiency

How much energy is used for transporting freight :

- **SUMMARY of energy efficiency**: door-to-door Combined Transport performs **45-72% better** in terms of energy efficiency than its unimodal trucking alternative.
- **Trucks**: 0,58-1,18GJ per tonnekilometer
- **Combined Transport**: 0,23-0,51GJ per tonnekilometer
- **FUTURE OUTLOOK**: the ongoing additional electrification of the European rail infrastructure network, including last mile lines to/from terminals, the electrification of intermodal transhipment technologies and the gradual introduction of battery-electric (BEV) trucks to perform Combined Transport road legs promises further advances by door-to-door Combined Transport in terms of energy efficiency per tonne-kilometer.
- **Reducing Europe’s dependency on imported fossil fuels**: in 2022 alone, Europe's bill for importing fossil fuels amounted to €640 billion, approximately 4.1% of its GDP. In 2023, even with lower prices, it remained close to 2.4% of the EU's GDP.

How to reduce the energy used per tonne-kilometre:

→ **Reduced resistance**: aerodynamic drag and lower rolling resistance.

→ **Reduced top-speed**: ’*slow steaming*’ is a concept known from shipping, where a relative small reduction in cruising speed can deliver a fuel saving of at least 15%.

→ **Longer and heavier vehicles**: the per-tonne kilometer energy efficiency of longer and heavier trucks and trains, as well as ever bigger waterborne vessels will be better.

→ **Better fuels (energy sources)**: high-quality fuel burns more completely, releasing more energy per unit of fuel. Lower-quality fuel, on the other hand, can lead to incomplete combustion, wasting energy and increasing emissions.

→ **Improved propulsion systems and electrification**: redesigned internal combustion and electric powertrains through using better materials, regenerative braking and more sophisticated control systems.

Present day comparative analysis

	1 Vienna – Melzo	2 Malmö - Duisburg	3 Rotterdam - Vienna	4 Cologne – Busto	5 Munich – Verona	6 Hamburg - Budapest	7 Valenton - Miramas	8 Dourges – Lyon	9 Ludwigsh. - Barcelona	10 Venlo – Poznan
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Energy efficiency (GJ/tkm)										
Unimodal trucking*	0,58 / 1,18									
Combined Transport*	0,24 / 0,34	0,32 / 0,51	0,23 / 0,33	0,26 / 0,37	0,25 / 0,36	0,29 / 0,42	0,32 / 0,47	0,32 / 0,46	0,28 / 0,41	0,27 / 0,39
CT advantage (%)	59% / 71%	45% / 57%	60% / 72%	55% / 69%	57% / 69%	50% / 64%	55% / 60%	55% / 61%	52% / 64%	53% / 67%

*energy use (GJ) per tonne-kilometer (tkm) performance in case of high density (heavy) cargo and average density (lighter) cargo

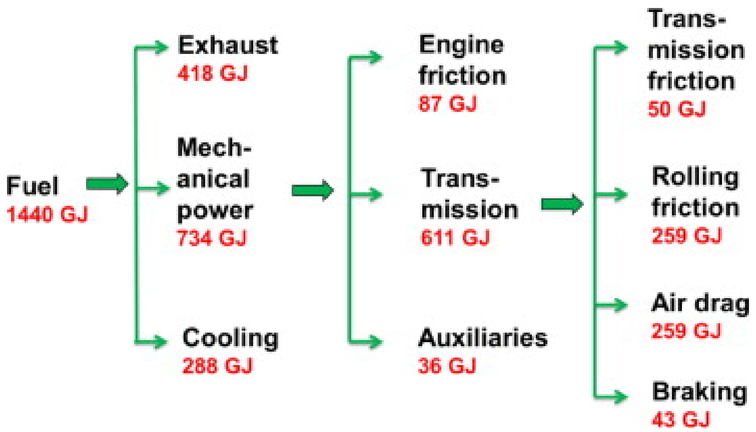
- **In case of heavy cargo** the energy efficiency of door-to-door Combined Transport compared to the unimodal road alternative was **45-60% better** where the difference was a factor of the length of the road legs.
- **In case of lower density (average) cargo** the energy efficiency of door-to-door Combined Transport compared to the unimodal road alternative was **57-72% better** where the higher values reflect the higher dead-weight ratio of trucks besides the length of the road legs.

Combined Transport's sources of energy efficiency

1. **Non-road modes of land transport:**
   - **Trains:** rail freight has several attributes that result in efficient energy use: (i) low friction: the friction between a rail wheel of steel and the rail of steel, a.k.a. „steel-on-steel" is much lower than the rubber-on-asphalt of trucks; (ii) platooning: a 740-metre-long intermodal freight train carries up to 50 truckloads of cargo in a „platoon" which reduces aerodynamic drag; (iii) dedicated infrastructue with active traffic control: if travelling on a well designed train path under the control of advanced traffic management, the number of start/stop operations and related braking of a freight train if far fewer than what trucks must endure; (iv) hybrid drive: freight trains utilising diesel locomotives are effectively using a hybrid system where the diesel engine is used to generate electricity which in turn powers the wheels – this solution allows economic engine operation that is superior to the direct internal combustion drives used by most trucks.
   - **Waterways**: inland barges and shortsea vessels that perform combined transport operations share the following energy efficiency attributes: (i) low friction: very low friction of steel-in-water compared to rubber-on-asphalt of trucks; (ii) large scale: inland vessels can carry 50-400 truckloads, while shortsea vessels may carry as many as a few thousand truckloads; (iii) minimalised start-stop operations: inland navigation or short sea shipping operations require very few stops along the way – all energy can be used to power the vessel forward.
2. **Electric power**:
   - **Trains**: electricity drives most trains, which entails numerous advantages: (i) inherent energy efficiency: an electric motor transforms 85-90% of the electrical energy input into useful mechanical energy, while an internal combustion engine is under 40%; (ii) power from the grid: electric locomotives do not need batteries since they receive power directly from the source through the overhead catenary wires; (iii) regenerative braking: electric powertrains enable regenerative braking, which energy is then fed back into the catenary by the locomotive.
   - **Waterways**: electric powertrains are in trial phase on waterborne vessels using a battery-based powertrain.
   - **Transhipment**: large intermodal terminals already use efficient grid-powered electric gantry cranes for transhipment. Horizontal transhipment techniques are also operated by electric power. Every type of mobile transhipment technology from terminal tractors to reachstackers and saddle carriers are now available with a battery-electric powertrain.
3. **Source of additional energy-efficiency improvements:**
   - **Trains**: while regenerative braking of wagons may also be possible, the true reserve in energy efficiency of electric-powered freight trains lies in the reduction of the number of breaking and restarts for traffic management reasons. Better train path design and punctual operations – assisted by digital systems – will deliver these in the future. Supplementary electric power from batteries enable electric locomotives to limited last-mile operations on sections of line not yet electrified.
   - **Waterways**: the use of larger vessels on inland waterways through ensuring greater water depth is the biggest source of additional energy efficiency improvements of waterway transport.
   - **Battery-electric propulsion**: electric trucks should be used in initial and final road legs of combined transport chains to deliver zero-carbon combined transport.

- **Greater vehicle size, lower friction and electric powertrains** make up the main sources of combined transport's energy efficiency.
- **Additional energy-efficiency improvements** will come from increasing the vehicles size, extending the overhead electricity supply to every railway line used by freight trains and

Improving energy efficiency in road transport

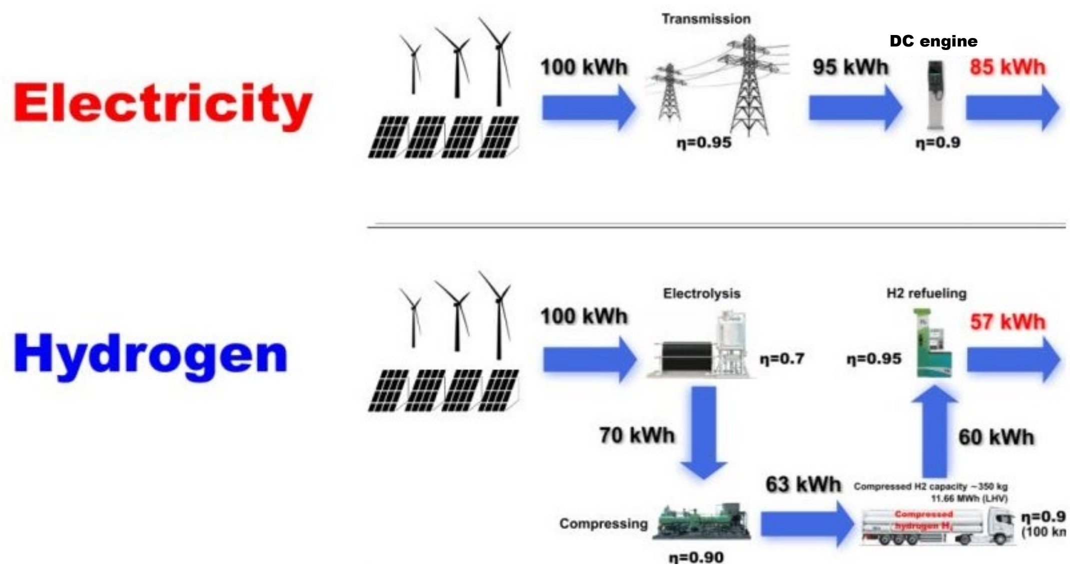


Fossil fuel use in a diesel internal combustion powertrain: **only 34% of the fuel energy is used to move the vehicle.**

1. **Aerodynamic drag and rolling resistance:**
   - **Aerodynamics:** reducing the wind resistance and the resistance caused by drag.
   - **Reduced friction:** friction in road transport describes the dichotomy between low resistance when wishing to advance while an excellent traction when changing direction (turning), or in case of braking, when the brake force has to slow the vehicle. In heavy duty vehicles, 33% of the fuel energy is used to overcome friction in the engine, transmission, tires, auxiliary equipment, and braking. The parasitic frictional losses, with braking friction excluded, are 26% of the fuel energy. In total, 34% of the fuel energy is used to move the vehicle.
2. **Slow steaming**: increasing speed often leads to an increase in energy consumption due to aerodynamic drag and rolling resistance, while slower speeds enable the optimisation of energy use. Reducing the cruising speed of a truck from 90 km/h to 80km/h can save at least 15% in fuel consumption.
3. **Longer and heavier**: extending the length and weight of trucks or trains is only limited by the available space and cost of the required adjustments to the infrastructure. Curves and inclines, spatial limitations in often historic urbanised areas, the need to preserve nature and respect for private property form the most substantial obstacles. Battery-electric powertrains in longer and heavier trucks may result in very heavy drive axles and overall high dead weight for these vehicles.
4. **Better fuels:**
   - **Higher cetane rating**: indicates the ability to ignite and burn cleanly. This results in improved combustion stability, better fuel efficiency, and reduced emissions.
   - **Diesel fuel additives**: additives can improve the cetane rating of the fuel resulting in smoother engine operation, reduce internal friction through enhanced lubrication and removal of deposits inside the engine.
5. **Improved propulsion systems:**
   - **Internal combustion engines**: continued engine design improvements by including improved materials and better control systems can deliver small improvements in efficiency. Electrification and hybridisation can offer additional benefits through recuperation of braking energy, but result in a much more complex propulsion system.
   - **Electric propulsion systems**: regenerative braking, instant torque and fewer moving parts form the basis of electric propulsion systems, which are in their infancy compared to internal combustion technology. Better energy management and propulsion control systems, improved material use and enhanced thermal management will all enhance the energy efficiency of today’s electric propulsion systems.

- **Reducing aerodynamic drag and rolling resistance** are inversely related to speed: only works if the vehicle is driving relatively fast, which in itself makes it energy inefficient.
- **Reducing cruising speed** is the most effective immediately available means of improving energy efficiency in trucking.
- **Fuel quality and additives**: most of present day fuels in Europe are of high quality and contain advanced additives – the reserves in this area are limited.
- **Development of propulsion systems**: after a century of development, not much reserves remain in the internal combustion technology; electric powertrains offer considerably better perspectives for marginal benefits per euro spent.

Hydrogen as a fuel in land freight transport



Comparison of an electric powertrain driven by electricity from the grid and a hydrogen-powered fuel-cell powertrain

1. **Energy efficiency:**
   - **Electric powertrain directly powered from the grid:** 85% of the eletricity is transformed into mechanical power – this is the system used by electric freight trains. In case a battery is used (i.e. in waterway vessels) a 10% charging loss is suffered.
   - **Hydrogen-powered fuel cell powertrain:** of 100kWh energy only 57kWh is delivered to the vehicle. The energy efficiency of a fuel cell powertrain is about 60%, therefore only 34% of the energy gets transformed into mechanical power, which constitutes a comparable energy efficiency to the better performing contemporaríy internal combustion enegines used in a direct drive configuration.
2. **Weight**: the weight of an electric powertrain driven by directly delivered grid electricity (as used on electric freight trains) is less than half as much as its matching hydrogen-powered fuel cell powertrain, which consists of the fuel cell stack, a hydrogen storage system and auxiliary systems such as air compressors, humidifiers, and cooling systems; the latter contribute considerably to the overall weight. A typical hydrogen-powered fuel cell powertrain also includes a considerably sized battery to enable regenerative braking. The additional weight of the powertrain reduces the useful load carrying capacity of the hydrogen fuel cell powered vehicle.
3. **Other considerations**: hydrogen is a very aggressive gas which requires special austenitic stainless steel tanks and pipes that are resitant to hydrogenic embrittlement. Austenitic stainless steels are highly resistant to corrosion, which is important for long-term durability and safety. If hydrogen is transported over long distances than compression is not enough, the gas needs to be cooled down to -253°C which turns it into a cryogenic liquid. The cooling requires significant additional energy, which further deteriorates the ultimate energy efficiency of hydrogen powertrains.

➢ **The energy efficiency of hydrogen-powered fuel cell powertrains is multiple times worse than direct grid-powered electric propulsion** or even battery-electric powertrains. The most energy efficient electric propulsion is used in railway transport, where the electric energy is drawn from overhead catenary network, which also can absorb electricity form regenerative braking. The second best solution for electric powertrains in transport are battery electric systems, which will continue to improve their performance with the advances of battery chemistry.

Comparative economic analysis of energy efficiency of freight transport over time

SHORT TERM

- **Quick win**: reduce the maximum speed of heavy trucks to 80km/h
- **Small improvement**: compulsory diesel additives
- **Gradual impact**: electrification of railway lines, terminals and trucks performing combined transport road legs
- **Big impact**: shift from unimodal trucking to combined transport

MEDIUM TERM

- **Continuous improvement:** electrification of railway lines, terminals and trucks performing combined transport road legs
- **Most promising**: development of electric powertrains and battery technologies
- **Big impact**: shift from unimodal trucking to combined transport

LONG TERM

- **TEN-T infrastructure parameters** on the railway network and modernised capacity management
- **Increased terminal capacities** and modernisation of terminals to match TEN-T parameters
- **Elimination of terminal white-spots** to connect regions by combined transport which today require longer road legs

The most potent energy efficiency improvement measures

- Uniform top speed for trucks at 80km/h
- Shift from unimodal trucking to combined transport
- Electrification of railway lines, terminals and trucks performing combined transport road legs.

2. Infrastructure efficiency

Heavy axles on the European road infrastructure:

- **SUMMARY of infrastructure efficiency**: total maintenance costs of Europe's motorways and main national roads stands at approximately €40 billion annually, while the railway network needs €22 billion in maintenance costs. While rail infrastructure maintenance costs are neutral to the nature of the traffic (passenger or freight), on the road infrastructure **each percentage reduction in heavy axle circulation delivers a substantial reduction in infrastructure deterioration, which this results in maintenance savings worth billions annually**.
- **On railways**: the infrastructure is designed and built for handling 22,5-tonne axles. Every locomotive, whether powering a passenger or a freight train, has 22,5t axles. Self propelled multiple units used in passenger transport may have somewhat lower axle loads. The range of axles running on rail weigh **between 18-22,5t**.
- **On roads**: 98% of road vehicles have axles of 5-tonnes or less. The dominant passneger car axles weigh 1-tonne**.** The range of axles on the road infrastructure is from **under 1-11,5t**, or even more. Constructing road infrastructure, including bridges, to withstand the loads caused by the heaviest permitted axles translates to substantial additional construction- and maintenance-costs.

Reduction of the impact of heavy axles:

→ **On railways**: the infrastructure is designed and built for handling 22,5-tonne axles, therefore a normal axle from the infrastructure's perspective is a „heavy axle".

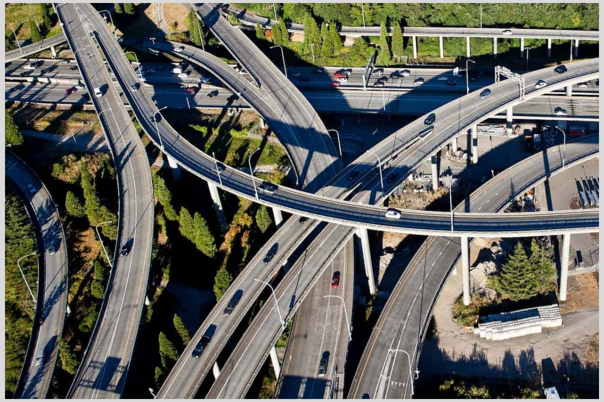
→ **Maximum allowed axle load**: refrain from increasing the haviest permitted axle load. Consider reducing the maximum allowed axle load. Implement a rigorous axle load enforcement regime with frequent measurement – if needed using on-board weight sensors.

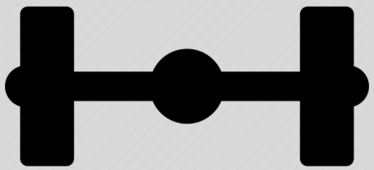
→ **Reinforce the road infrastructure**: roads and bridges could be strengthened to reduce the degradation caused by heavy axles.

→ **Reduce the vehicle kilometers perfomed by heavy trucks**, which is easiest done through a shift from unimodal trucking to combined transport, which operates with short initial and final road-legs, while utilising modes such as electric rail freight and waterborne means, which are ideally suited to supporting heavy weights.

Heavy axles on Europe’s transport infrastructure

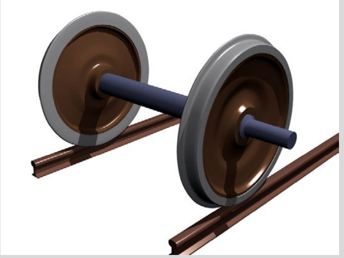
- **Main cause of deterioration**: axle loads of heavy trucks are the main cause of deterioration of road pavement structures.
- **Overloaded trucks** found during roadside checks throughout Europe varies depending on the country, region, and specific enforcement efforts. However, studies and reports have shown that the percentage of overloaded vehicles can range from **2% to 18%**, with some sources suggesting that the average rate is around **10%.**
- **Deterioration of bridges**: heavy trucks play a significant role in the deterioration of bridges; here is how:
  - **Excessive Weight**: Overloaded trucks put immense stress on bridges, exceeding their design capacity. This leads to accelerated wear and tear, causing cracks, structural damage, and ultimately, bridge failures.
  - **Vibrational Stress**: The constant vibration caused by heavy trucks traveling over bridges can weaken the structure over time. This is particularly damaging for older bridges that may already have underlying structural issue.
- **Circulation of heavy trucks**: based on Eurostat data and other industry reports, it is estimated that heavy trucks in Europe cover billions of vehicle kilometres annually.
- **Heavy axles on the rail infrastructure**: there are no heavy or light axles on the railway infrastructure – just average axles.





1 – 11,5t

(98% of vehicles less than 5t)



18 – 22,5t

(90% of trains 22,5t)

Infrastructure efficiency in long-distance freight transport

Infrastructure efficiency means that the performance of the freight transport operation does not unduly degrade the infrastructure requiring frequent and extensive maintenance.

- **The road infrastructure** has been tasked through legislative decisions to withstand a gradual increase of maximum allowed axle loads over the years, beginning with 9 tonnes per axle, which was gradually increased to today's 11,5 tonnes. The current revision of the Weights and Dimensions Directive floats the idea of even 12,5-tonne drive axles. Reinforcing the road infrastructure to enable it to withstand the wear and tear of the ever heavier axles is very costly and often not feasible. This results in accelerated degradation and the need for frequent and ever more costly maintenance; maintenance works that cause excessive congestion.
- **The railway infrastructure** is built to support 22,5-tonne axles. Moreover, the technical enhancement of rail infrastructure to bear heavier axles is relatively easy and straightforward.
- **Waterways** can support any weight constrained only by the available water-depth and the height of bridges.

The goal from an efficiency and competitiveness viewpoint should be to satisfy Europe's freight transport needs with the smallest negative consequence on the transport infrastructure causing the lowest possible expenses to public budgets.

Reinforcing roads: could this be an option?

1. **Pavement Thickness:**
   - **Increasing Asphalt Layer Thickness:** Adding more layers of asphalt can increase the road's load-bearing capacity.
   - **Thicker Concrete Slabs:** For concrete roads, increasing the slab thickness can improve its strength and durability.
2. **Pavement Material:**
   - **High-Strength Asphalt:** Using asphalt with higher strength and durability can improve the road's ability to withstand heavier loads.
   - **Concrete with Enhanced Strength:** Incorporating stronger concrete mixes or using fibers for reinforcement can enhance the concrete's load-bearing capacity.
3. **Road Base:**
   - **Thicker Base Layers**: Increasing the thickness of the base layers, such as crushed stone or gravel, can provide better support for the pavement.
   - **Higher-Quality Base Materials**: Using higher-quality base materials with better load-bearing properties can strengthen the road structure.
4. **Bridge Reinforcement:**
   - **Strengthening Existing Bridges**: This can involve adding structural elements like steel beams or concrete overlays to increase the bridge's load-carrying capacity.
   - **Building New Bridges**: Constructing new bridges with higher load-bearing capacities can accommodate heavier trucks.
5. **Road Design:**
   - **Wider Shoulders**: Wider shoulders can accommodate larger vehicles and reduce the stress on the pavement edges.
   - **Reduced Grades**: Less steep grades can reduce the stress on the road surface, especially during heavy traffic.
   - **Improved Drainage**: Proper drainage can prevent water damage and erosion, which can weaken the road structure.
6. **Regular Maintenance:**
   - **Frequent Inspections**: Regular inspections can identify potential problems early and allow for timely repairs.
   - **Preventive Maintenance**: Regular maintenance, such as patching potholes and resurfacing, can extend the life of the road and improve its load-bearing capacity.

➢ **Expensive and long-term investments** only to achieve a marginal improvement in the performance of heavy trucks, which could be easily replaced by combined transport. Combined transport requires far fewer and less expensive investments – if any – to deliver results that far outperform anything technically feasible on road.

Comparative economic analysis of the infrastructure efficiency results

- **The cost of maintenance of Europe's 376.500km of motorways and national through roads is estimated* to be <u>€40 billion</u>**

  NOTES: (1) the estimated amount is likely insufficient based on the severe degradation of roads and bridges throughout the European Union; (2) the „main cause of deterioration" of roads and bridges are the axle loads of heavy trucks; (3) the €40 billion figure does not include the maintenance costs of several million kilometers of lower level roads which are instrumental to getting trucks to their final desitnation (4) part of the fuel excise duty and the vehicle taxes collected from motorists should be used to maintain and to develop the non-tolled road network, however these funds are inadequate to cover the related expenses, especially in case the various external costs of road transport would need to be covered from the same excise duty revenues.

- **The cost of maintenance and renewals of Europe's 202.000km of rail infrastructure – used by 1,5 million freight trains and over 12 million passenger trains annually – stands at <u>€22 billion</u>**

  NOTES: (1) the €22 billion includes every meter of the railway infrastructure; (2) freight trains and passenger train axles have similar weight, therefore they cause equal wear and tear; (3) doubling the number of freight trains or freight train kilometers performed on the European railway network would not result in higher maintenance expenses of the infrastructure.

SUMMARY: A substantial reduction in the number of vehicle kilometres performed by heavy trucks would result in a significant slowing of the degradation of the road infrastructure, while in case the cargo was shift to combined transport, the additional freight train kilometres will <u>not cause</u> any increase in the wear and tear of the rail or waterway infrastructure.

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* based on Germany's €5 billion budget on its 51.000km network in 2025, does not include the upkeep of lower-level roads under regional or municipal government management

3. Labour efficiency

Manhours per cargo movement:

The number of direct man-hours + overhead hours per cargo movement described based on the 10 representative relations used during the modelling [see details on the next slide].

- **Summary labour efficiency**: door-to-door Combined Transport's labour productivity in comparison to unimodal trucking:

average labour productivity advantage: **60%**

(range of labour productivity advantage on the 10 representative relations 42 - 80%)

Major influencing factors:

1. **Length of the Combined Transport road-legs**: the longer the road legs the less the labour productivity advantage
2. **The length of the non-road leg**: the longer the non-road leg, the greater the advantage of Combined Transport

How to improve tkm/employee in freight transport:

→ Reduced empty runs

→ Increased vehicle size/capacity

→ Self-drive technology (on all modes)

→ Reduced congestion (on roads) or increased number and quality of train paths (for freight trains) – leading to higher average speeds

→ Increased density of intermodal terminals to be able to go closer to the origin/desitnation points resulting in reduced road legs

Labour efficiency: unimodal trucking vs combined transport

	1 Vienna – Melzo	2 Malmö - Duisburg	3 Rotterdam - Vienna	4 Cologne – Busto	5 Munich – Verona	6 Hamburg - Budapest	7 Valenton - Miramas	8 Dourges – Lyon	9 Ludwigsh. - Barcelona	10 Venlo – Poznan
Distances										
Unimodal trucking	856 km	1166 km	1197 km	832 km	403 km	1241 km	772 km	684 km	1226 km	865 km
CT road leg 1	13 km	278 km	29 km	19 km	14 km	5 km	22 km	33 km	70 km	45 km
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CT rail leg	823 km	922 km	1180 km	838 km	441 km	1208 km	709 km	631 km	1342 km	847 km
Manhours per cargo movement										
Unimodal trucking	21,6	29,4	30,2	21,0	10,2	31,3	19,5	17,3	31,0	21,9
Combined Transport	5,2	12,2	6,0	7,7	3,4	11,5	9,1	7,4	10,0	7,1
CT advantage (%)	**69%**	**42%**	**80%**	**64%**	**66%**	**63%**	**53%**	**57%**	**68%**	**67%**

Conditions of the model:
- Average speed of unimodal trucking: 70km/h*
- Average speed of combined transport road leg (on road legs up to 50km): 20km/h**
- Average speed of intermodal freight train: 30km/h***
- Terminal processing, including administrative and overhead allowance: 1,5 manhours per consignment
- Overhead hours per direct manhour: 20%

* reflects the mandatory rest times of 45min per each 4,5 hour driven
** the 20km/h average speed includes the waiting times at terminals and the mandatory rest times of 45min per each 4,5 hour driven
*** includes waiting times prescribed in the train paths

Sources of labour efficiency in combined transport: present and future

1. **Vehicle size in the present and in the future:**
   - **Trains:** 740m long trains along the entire TEN-T network (carrying 42-50 truckloads) with a single train driver and the occasional connection of two 740-metre-long trains for further labour economies
   - **Waterways:** presently between 50-400 truckloads per inland waterway vessel; the average capacity of inland vessels could increase if the waterway infrastructure could permit it.
   - **Trucks**: 1 driver per consignment, however in case EMS trucks of 25,25m or 30m length were used in those initial- and/or final road legs of combined transport chains where the infrastructure permit it the number of truckloads per driver could increase from 1 to 1,5-2.
2. **Self-drive automation technology:**
   - **Trains and waterborne vessels** could benefit from self-drive technologies, though on seafaring vessels a crew would still be required for safety reasons
   - **Trucks**: self-drive possible only in few cases of combined transport road legs since the driver must perform several non-driving functions that cannot be automated.
   - **Transhipment**: crain operation and parts of road and rail vehicle inspection can be automated.
3. **Digitalisation and better organisation:**
   - **Load factors** of every transport mode used in combined transport can be improved through better organisation supported by digital solutions.
   - **Transhipment**: shorter processing times can be achieved in terminals reducing the live labour needs.

Sources of labour efficiency in combined transport: present and future

- **Increased vehicle size**: intermodal freight trains can carry 42-50 truckloads with a single driver, while inland waterway vessels can carry 50-400 truckloads with a single driver + a crew of 1-2 persons. Shortsea vessels can carry up to 1-2 thousand truckloads of cargo with a small crew of 5-10 seamen.
- **Self-driving**: development work is under way to realise self drive in all three modes; the automatisation of short combined transport road legs will be problematic due to the varied non-driving tasks of the driver.
- **Digitalisation and better organisation**: increasing the load factor as well as certain transhipment functions can be improved through digitalisation and better organisation.

Technical solutions to boosting labour efficiency per mode

Potential improvements of transport safety:

1. **Vehicle- and train-length improvements and effective speed:**
   - **Length and weight**: longer trains (740m is the TEN-T train-length parameter vs the currently typical 500-600m) and longer trucks (EMS combinations) – increased axle loads of EMS combinations, especially if equipped with an alternative powertrain, as well as energy efficiency concerns go against EMS
   - **Speed:** average speed is key vs maximum speed; the reserve for trucks is limited – especially when viewed from the most productive energy efficiency improvement perspective of *slow-steaming*; the potential for increasing the average speed in intermodal rail freight is much greater in view of the present day actuals – specifically through providing freight trains with more and better quality train paths, which do not require additional investments into the rail infrastructure.

2. **Road infrastructure:**
   - **Increased maximum safe speed:** increasing the safe travel speed of road vehicles is problematic due to the controversial relationship between rolling traction and braking: for speed and energy efficiency low friction is needed, but in order to stop effectively the reverse is sought after.
   - **Longer and heavier trucks:** significant investments into the road infrastruture would need to enable the safe circulation of EMS trucks of 25m or 30m length ranging from truck parkings and motorway rest areas through ramps and safety lanes to roundabouts. The higher axle loads of drive axles on trucks equipped with alternative powertrains will require expensive reinforcement of pavements, or else these will result in accelerated road degradation adding to the needs for maintenance works.

3. **Rail infrastructure:**
   - **Increased maximum safe speed**: the gap between the presently allowed top speeds of 100-120km/h and the achieved average (timetable) speeds is significant, which indicates that management action (=better timetabling and traffic management) could enable a much improved preformance without any costly investment.
   - **Longer and heavier trains**: enabling the circulation of 740-metre-long freight trains is the agreed TEN-T parameter that requires a relatively modest investment.

4. **Other means of boosting labour efficiency:**
   - **Self-drive technology**: self-driving is under development both on road and rail transport; the technology is quite far from proving its safety for public proliferation. Numerous R&D projects are running in both modes, as well as on waterway transport. The circulation of self-driven vehicles is foreseen as feasible only in the long run.
   - **Increased density of transhipment terminals**: the upgrading of existing transhipment terminals as well as the opening of new terminals is an intensely pursued activity be intermodal sector stakeholders, which results in 5-10 new terminals opening each year and several times as many completing capacity and capability enhancement projects. Capacity development of existing or the construction of new intermodal terminals is a relatively quick and inexpensive way of enhancing combined transport.

Comparative economic analysis of the labour efficiency results

- **The labour productivity advantage of combined transport compared to its unmiodal trucking alternative is around 60% today.**

  NOTE: the shorter the intitial and final road legs of the combined transport chain the greater overall the labour productivity advantage.

- **The most effective sources of labour productivity increase can come from: (1) shorter combined transport road legs – enabled by an improved terminal density; and (2) reduced congestion on motorways, which are often a result of excessive maintenance needs and/or accidents.**

  NOTES: (1) intermodal stakeholders are actively investing in both upgrading existing terminals, as well as into opening new transhipent terminals; (2) motorway maintenance needs can be reduced by a substantial reduction of the circulation of heavy trucks with heavy axles and by the reduction of road accidents.

SUMMARY: The upside potential of labour productivity enhancement is with combined transport, which already outperforms unimodal trucking by 60% on average.

4. Safety efficiency

Accidents on the European transport network:

- **SUMMARY of safety efficiency**: cost of accidents show a 100-fold difference while in the transport performance is 5-fold if expressed in tonne-kilometres, resulting in **a 20-times better performance** of rail freight in terms of euros per year.
- **Trucking**: The yearly 3.000 fatalities attributable to heavy goods vehicles (HGVs) carry a total cost of €21,6 billion, while the 21.000 serious injuries another €25,2 billion. The property damage related to road accidents being roughly equal to the cost of serious injuries, which makes the total of these three equal to **€72 billion**.
- **Rail**: There are no statistics produced for rail freight-related accidents, fatalities or injuries, but it is assumed to be a small fraction of the total. 808 fatalities and 594 serious injuries were recorded in 2022 in the entire railway sector – inluding both passenger and freight services. Excluding fatalities of trespassers and suffered at level crossings, the railway system was found to have been responsible for 7% of the accident occurrences. The full cost of the 1597 railway accidents recoded in 2022 was calculated at **€4 billion**.
- **Waterway**: EU maritime sector fatalities count in the 10-12 range. There is no systematic monitoring and reporting of inland waterway accidents andfatalities, serious injuries or material damage cuased.

Reduction of the impact of accidents:

In 2018, the EU has set itself a 50% reduction target for road deaths – and, for the first time, also serious injuries – by 2030. This was set out in the Commission's Strategic Action Plan on Road Safety and EU road safety policy framework 2021-2030 which also lay out road safety plans aiming to reach zero road deaths by 2050 (‘Vision Zero’).

→ Addition of active and passive safety technologies to road vehicles: assisting the driver and reducing the adverse impact of accidents.

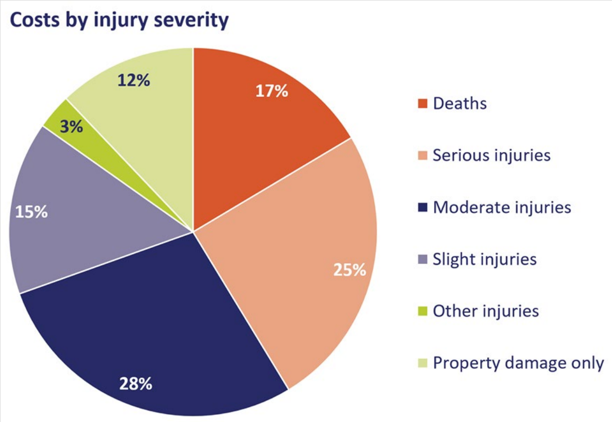
→ Addition of safety features to the infrastructure: passive infrastructure improvements, maintenance, enforcement and active digital systems.

→ Improved operating methods and enforcement: technology to prevent fatigued driver from handling a vehicle, smart tachographs to transmit data to enforcement bodies, self driving / machine driving.

On rail, the implementation of active train control (ERTMS) as agreed in the TEN-T Guidelines Regulation (1679/2024) will eliminate most remaining human risk factors behind railway accidents. This will be completed by the rigorous vehicle and infrastructure maintenance practices.

→ Organic developments will prevent the few railway accidents of today.

Safety in long-distance freight transport: road performance



1. **Crashes with heavy goods vehicles** (HGVs) lead to around 14% of road fatalities in the EU, i.e. over 3000 fatalities in 2019. The fatality risk (number of fatalities per distance driven) is substantially higher for HGVs as compared to other road users. HGVs and buses/coaches are particularly dangerous for other road users: around 90% of fatalities in HGV crashes and around 80% of fatalities in bus/coach crashes occur to other road users. HGV crashes occur relatively often on motorways. However, most of the fatal HGV crashes occur on rural roads.

2. **Crash characteristics**: The mass, maneuverability, and acceleration and deceleration characincreasedstics of the vehicle make road infrastructure particularly critical for HGV and bus safety. Long braking distances, burst tires, and, for HGVs, overload or unbalanced load can also have a detrimental effect on safety. In addition, other road users may be insufficiently aware of the specific characteristics of HGVs and buses, including their large blind spots. The vast majority of fatalities and serious injuries in HGV-related crashes affect the crash opponent rather than the occupants of the HGV. The reason for this is that HGVs are much heavier than most other road users. It is a physical law that, if two vehicles collide, most of the energy released is absorbed by the lighter crash partner. As a result, the lighter vehicle will be more damaged, and its occupants or riders more seriously injured. EU-wide almost 90% of fatalities in HGV crashes were other road users, mainly car occupants (EC, 2021a).

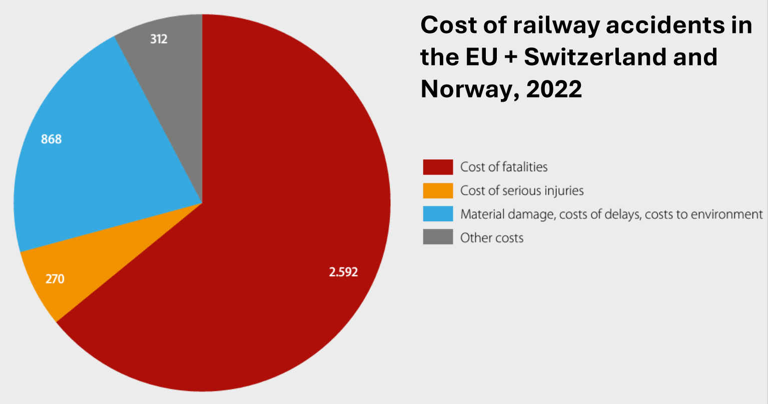
3. **Cost of road accident fatalities and serious injuries**: According to the European Commission, there were on average 7 serious injuries for each road fatality on European roads in 2019. The costs amount to about €7.2 million per road death and €1.2 million per serious road injury. The yearly 3.000 fatalities attributable to HGVs carry a total cost of €21,6 billion, while the 21.000 serious injuries another €25,2 billion. The property damage related to road accidents being roughly equal to the cost of serious injuries, which makes the total of these three equal to €72 billion.

4. **The human factors that affect crash risk** generally also apply to professional drivers. These include excessive and inappropriate speed, driving under the influence, tailgating, etc. Professional drivers are, more than non-professional drivers, prone to fatigued and distracted driving. International drivers often have to sleep in their truck. Overall, this makes professional drivers particularly prone to fatigue and distraction as well as to health conditions that might affect safe driving, e.g. sleep apnoea.

5. **EU goals**: At its current rate, and without additional efforts, the EU and Member States are unlikely to meet the 2030 intermediate objective, thus casting doubt on the ability to achieve the 2050 objective. The number of fatalities would drop only by a quarter as opposed to a half by 2030 (compared to 2019 values, which is the baseline chosen by the Commission to measure progress). The objective for serious injuries also appears to be hard to achieve. Meeting these objectives may become more difficult as it becomes increasingly hard to achieve significant improvements from what is an already good performance level. For example, between 2010 and 2022 the best performing member state in terms of reducing fatalities was Lithuania (- 60%), the country with the seventh-highest fatality rate in 2010, while fatalities in the Netherlands, the country with the third-lowest fatality rate in 2010, actually intensified by 22%.

➢ **The fatality risk of accidents involving HGVs is substantially higer than other road users** and it is chronically difficult to reduce due to the physics of heavy weight and speed. The human factor has been identified as the prime reason for accidents involving heavy trucks, especially those travelling on long distances. The different driver assisting systems introduced over the years have not been able to reduce accident risk in the ever denser traffic on Europe's roads.

Safety in long-distance freight transport: rail and waterway performance



1. **Railway accidents in the EU** + Switzerland + Norway numbered 1597 instances in 2022, resulting in 808 fatalities and 594 serious injuries. 518 fatalities (64%) were „unauthorised persons on railway premises" (trespassers).
2. **Accident characteristics**: if excluding unauthorised persons and level crossing accidents (31%), about 7% of loss of lives on EU railways in 2022 were internal to railway operation (passengers, employees and other persons). The EU Agency for Railways does not report accidents and fatalities accourding to the type of train service (passenger or freight). Freight trains, slower than passenger services, are handled by considerably fewer employees, hence it is assumed that only a small fraction of accident injuries or fatalitis were attributable to freight trains. The active safety systems of railway transport prevent most accidents.
3. **Cost of rail accident fatalities and serious injuries**: The total costs of accidents were calculated at €4 billion. Only a fraction of these were attributable to freight trains.
4. **Maritime accidents:** 12 persons lost their lives in maritime accidents involving ships registered in EU countries in 2023, down from 30 in 2022. Out of the 12 fatalities in accidents involving EU-registered vessels in 2023, 10 occurred in EU seas. In 2023, 5 persons were killed in accidents involving EU-registered cargo ships. There is no European level data collection of inland waterway accidents and fatalities.
5. **Costs of EU maritime accidents:** There is no data collection and publication of data for the extent and costs of maritime and inland waterway accident costs.
6. **EU goals**: Considering the relatively low level of rail and waterway accidents in the European Union, the Member States saw no need to specify a target for their reduction.

➢ **The very low level of rail freight and waterway accidents** did not make it necessary to introduce any targeted action or programme for their recuction as the already agreed introduction of ERTMS signalling and the ever stricter enforcement is seen to eliminate the causes involved. Rail and waterway ccident follow-up actions similar to those in the aviation sector ensure that each unfortunate occurrence contributes to the prevention of any recurrence.

Technical solutions to boosting transport safety

Potential improvements of transport safety:

1. **Vehicle improvements:**
   - **Passive**: camera systems to eliminate blind spots of HGVs, collision sensors and other driver assist systems, on-board weight sensors to reduce total mass.
   - **Active**: reduced maximum speed, stricter conditions for drivers' licenses, stricter enforcement of (i) roadworthiness including the condition of tyres, (ii) driving and resting times of professional drivers, as well as (iii) quality of the rest. Continuous driver training is a must to keep control over the human factor of accidents.
2. **Road infrastructure:**
   - **Passive**: rebuilding sharp bends, widening narrow driving lanes, extending short entry and exit ramps to motorways, rebuilding roads to reduce the steepest slopes, enhanced spatial illumination, regular maintenance to replace worn pavement signals, eliminate road surface uneveness.
   - **Active**: illuminated lane guidance, enhanced road-infrastructure operation to minimise slippery road surfaces, active speed allowance management.
3. **Trains:**
   - **Passive**: prudent predictive maintenance of rail vehicles can effectively reduce defects that may cause an accident.
   - **Active**: the installation of ERTMS on the TEN-T rail network will materially reduce any remaining human factor of railway accidents.
4. **Rail infrastructure:**
   - **Passive**: prudent predictive maintenance of the railway infrastructure can prevent the occasional accident that is related to the condition of the infrastructure.
   - **Active**: responsible operation of the railway infrastructure (traffic management) aided by digital solutions (IT and communication systems) will effectively reduce any remaining accident risk.
5. **Waterway vessels:**
   - **Passive**: prudent preventive maintenance practices can effectively reduce the defects that may cause the occasional waterway accident.
   - **Active**: training and responsive operational practices, aided by digital solutions, as well as training will effectively reduce any remaining accident risk.

The most potent transport safety improvement measures

- **Road**: costly infrastructure reconstruction and expensive vehicle technologies presently still in development phase will be needed to reverse the currently high risk profile.
- **Rail**: introduction of ERTMS signalling, as well as organic digitalisation solutions together with responsible traffic management practices will eliminate the minimal existing risks.
- **Waterways**: predictive maintenance and the organic developments in vessel operations will eliminate the minimal existing accident risks.

Comparative economic analysis of the safety efficiency results

- **The accident rate of door-to-door combined transport is 20-times lower than its unimodal trucking alternative. The difference has been quantified as €70 billion annually, bulk of which is absorbed by social security and other public budgets.**

  NOTE: the €70 billion figure does not include the congestion impact of accidents, which consists of €21,6 billion for fatalities, €25,2 for serious injusries and €23,2 billion for the damage and loss of property.

- **The most effective sources of road accident prevention are: (1) redesigning and complementing road infrastructure; (2) driver assist systems built into vehicles; (3) reduced maximum speed; (4) strict enforcement using digital solutions.**

  NOTES: (1) intermodal stakeholders are actively investing in both upgrading existing terminals, as well as into opening new transhipent terminals; (2) motorway maintenance needs can be reduced by a substantial reduction of the circulation of heavy trucks with heavy axles and by the reduction of road accidents.

- **The rail and waterway accident prevention – from the very low levels recorded for these two mores of transport – is being delivered through (1) the installation of ERTMS signalling; (2) prudent predictive maintenance, and (3) consistent routine safety training.**

  NOTES: the identified measures are already part of the routine safety enhancement programmes of railway and waterway operators.

SUMMARY: Expensive and time consuming changes would need to be implemented to reduce road-accident occurrences and to eiminate the €70 billion cost of accidents related to HGVs. In railway and waterway operations, the comparably much lower level of accidents will be eliminated through alreadyy running routine safety enhancement programmes. The most inexpensive road accident prevention method is a shifting of transportation by unimodal truck to door-to-door combined transport.

5. Environmental and climate efficiency

Environmental and climate efficiency:

- **SUMMARY of environmental efficiency**: contemporary door-to-door combined transport emits **79% fewer** pollutants and greenhouse gases when carrying heavy cargo and **84% fewer** pollutants and greenhouse gases when transporting average cargo compared to the performance of unimodal trucking of the same.
- **The costs of HGV pollutant emissions** amounts to €13,9 billion annually according to the 2019 edition of the CE Delft Transport Externality Handbook. Each 100 billion tonne-kilometres of unimodal trucking shited to combined transport can save €700 million of expenses currently underwritten by public and social security budgets.
- **Greenhouse gas emissions** are assumed to be effectively internalised through the ETS2 (Emission Trading System for Transport) system. HGVs produce €0,004-0,007 worth of greenhouse gases per tonne-kilometre according to the marginal values established in the 2019 edition of the CE Delft Transport Externality Handbook, which amount to about €10 billion annually.

Reduction of environmental and climate impacts:

On 26 October 2022, the European Commission tabled its proposal for a revision, merging the two EU Ambient Air Quality Directives into a single one. While introducing a zero-pollution objective for air, to be achieved by 2050, the proposed directive would set interim 2030 EU air quality standards that are closer to WHO guidelines. For instance, the annual limit value for PM2.5 would be reduced from 25 μg/m^3 to 10 μg/m^3 in 2030 (WHO guideline is 5μg/m^3).

→ Reduction of harmful pollutant emissions in freight transportation by 60-80% will only be possible if a paradigm shift is carried out: internal combustion technology – even if using carbon-neutral fuels – will never be capable of delivering the required values.

→ Only modal shift from unimodal truck transport to door-to-door combined transport can promise the kind of reduction required to achieve the targeted ambient air quality standards in Europe.

→ Zero carbon combined transport, where battery-electric trucks are used in the initial and final road legs can deliver a pollutant emission reduction greater than 90%.

Environmental and climate efficiency in long-distance freight transport

Environmental and climate efficiency means that the performance of the freight transport operation causes minimal or no adverse impact on the environment and the climate.

- **Pollution** is a stubborn byproduct of transport through the emission of gases, particles and noise harmful to human and animal health as well as to the vegetation.
- **Emission of greenhouse gases** that are otherwise not poisonous, such as CO_2, have been proven to result in climate change that has an adverse effect of the habitability of the planet, as well as increases the occurrence of adverse weather phenomena negatively impacting the safety of humans, animals and vegetation.
- **Noise emissions** result in stress for both humans and animals, adversely affecting concentration and rest.

Combined transport effectively inserts non-road modes of transport into transport-chains presently handled by unimodal trucking through the use of intermodal transhipment techniques. Non-road modes of transport, primarily electric rail freight, as well as waterborne means of transport, bring an improved environmental and climate performance.

Present day comparative analysis

	1 Vienna – Melzo	2 Malmö - Duisburg	3 Rotterdam - Vienna	4 Cologne – Busto	5 Munich – Verona	6 Hamburg - Budapest	7 Valenton - Miramas	8 Dourges – Lyon	9 Ludwigsh. - Barcelona	10 Venlo – Poznan
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CT rail leg	823 km	922 km	1180 km	838 km	441 km	1208 km	709 km	631 km	1342 km	847 km
CO_2 emission (g/tkm)										
Unimodal trucking*	40 / 82									
Combined Transport*	8 / 11	14 / 24	8 / 11	8 / 13	8 / 12	11 / 17	5 / 9	5 / 8	5 / 7	13 / 18
CT advantage (%)	80% / 87%	65% / 71%	80% / 87%	80% / 84%	80% / 85%	72% / 79%	87% / 89%	87% / 90%	87% / 91%	67% / 78%

*CO_2 emission per tonne-kilometer (tkm) performance in case of high density (heavy) cargo and average density (lighter) cargo

- **In case of heavy cargo** the CO_2 emissions of door-to-door combined transport was **on average 79% lower** than unimodal trucking.
- **In case of lower density (average) cargo** the CO_2 emissions of door-to-door combined transport was **on average 84% lower** than unimodal trucking
- **The emission of other pollutants** (NOx, PM2,5/PM10 and noise) is proportional to the CO_2 emissions, therefore a **79-84% average reduction** of these pollutants could be expected.

Expected impact of future technologies on the environment and climate impacts

1. **Alternative propulsion systems for pollutant and greenhouse gas emissions:**
   - **Electric powertrains**: perform best in trains which obtain the electricity through an overhead catenary which can also handle the electricity feed-back during regenreative braking. In all other modes a battery will be required, which involves a manufacturing and recycling process with a singificant environmental and climate footprint.
   - **Carbon-neutral fuels for internal combustion engines**: while greenhouse gas emissions can be minimised through the use of these fuels, the internal combustion-related NOx and particulate emissions remain.
   - **Hydrogen in a fuel-cell powertrain**: the highly complicated hydrogen fuel-cell powertrains involve a manufacturing and recycling process with a singificant environmental and climate footprint. Rubber-on-asphalt operations continue to produce particulate matter emissions.

2. **Noise emissions:**
   - **Electric powertrains**: electric powertrains in every mode result in a considerably lower noise emission.
   - **Passive noise protection**: localised noise protection is possible in case of railways, road and certain inland waterways.

3. **Emission of particulate matter:**
   - **Regenerative braking**: the particulate matter emission of friction brakes can be significantly reduced by the use of regenerative braking, as well as through efficient traffic organisation and reduced congestion that requires frequent braking.
   - **Traction**: Rubber-on-asphalt operations continue to produce particulate matter emissions. Steel-on-steel operation of railways produce minimal harmless iron particles.

The most potent environment and climate impact improving technologies:

- **Electric powertrains**: in every mode, though they perform best if not using a battery, but rely on direct grid power deliver.
- **Passive noise protection**: to complement electric powertrains in reducing transport noise emissions.
- **Regenerative braking**: will eliminate friction related brake-lining emissions. Traction related rubber particles will always be emitted by road transport.

Comparative economic analysis of the environmental and climate efficiency results

- **The environmental productivity advantage of combined transport compared to its unmiodal trucking alternative is between 79-84% today.**

  NOTE: based on the proportionality principle.

- **The costs of pollutant emissions in the European Union based on the CE Delft Transport Externality Handbook are €133,3/1000g of pollutants.**

  NOTES: The calculation of pollutant emissions was based on Table 14 and takes into account only the rural values for NOx and PM2,5 since the combined transport road legs are carried out by similar trucks to those used in unimodal truck transport. Accordingly the €/1000g emission figures are:

  €17,5 (NH_3) + €10,9 (SO_2) + €12,6 (NOx) + €70 (PM2,5) + €22,3 (PM10) = **€133,3**

- **The pollution cost of HGVs is €0,0938 per vehicle-kilometre translates to about €7 billion for the estimated 1000 billion HGV tonne-kilometres performed on distances longer than 300km in Europe.**

- **The greenhouse gas emissions of HGVs according to marginal values established in the 2019 edition of the CE Delft Transport Externality Handbook amounted to about €10 billion annually. These should be internalised through the ETS2 (Emission Tranding System for Transport during the coming years).**

SUMMARY: Assuming that the greenhouse gas emissions of truck transport will be effectively internalised through the ETS2 (Emission Trading System for transport), each 100 billion tonne-kilometres of truck transport shifted to combined transport will result in a saving of €700 million annually.

Conclusions and outlook

Competitiveness boosting through combined transport if it was to become the backbone of land freight transport on distances of 300km or longer in the European Union:

- Energy- and labour efficiency, as well as uncharged external cost-related efficiencies of combined transport operations over their unimodal trucking alternative on distances of 300km or more amount to **€132 billion annually** for the European economy, which figure was partially counted with prices from the 2019 CE Delft Transport Externality Handbook).
- The road congestion reduction impact that would follow this change has been estimated at **€90 billion annually**.
- €70 billion worth of fossil fuel imports could also be saved **contributing to the Europe's balance of payments**.

How can Combined Transport become the backbone of longer-distance European freight transport:

No need for significant public or private investments.

→ The estimated annual public investment need into the TEN-T transport infrastructure stood at **€15 billion**, which is about 11% of the current annual spending.

→ The estimated annual private investment into various intermodal assets like terminals, rolling stock and digitalisation amounts to **€1,5 billion**, which is about equal to what the sector spends annually.

→ The European and member state legislators will have to make adjustments to the regulatory framework primarily to ensure that cross-border intermodal freight trains are granted **more and better quality train paths**, as well as that the **hierarchy of these trains is elevated** in the eye of rail traffic managers.

→ **Standardisation and digitalisation** in the field of railway transport would need to be advanced throughout Europe.

Comparative economic analysis of total efficiency results

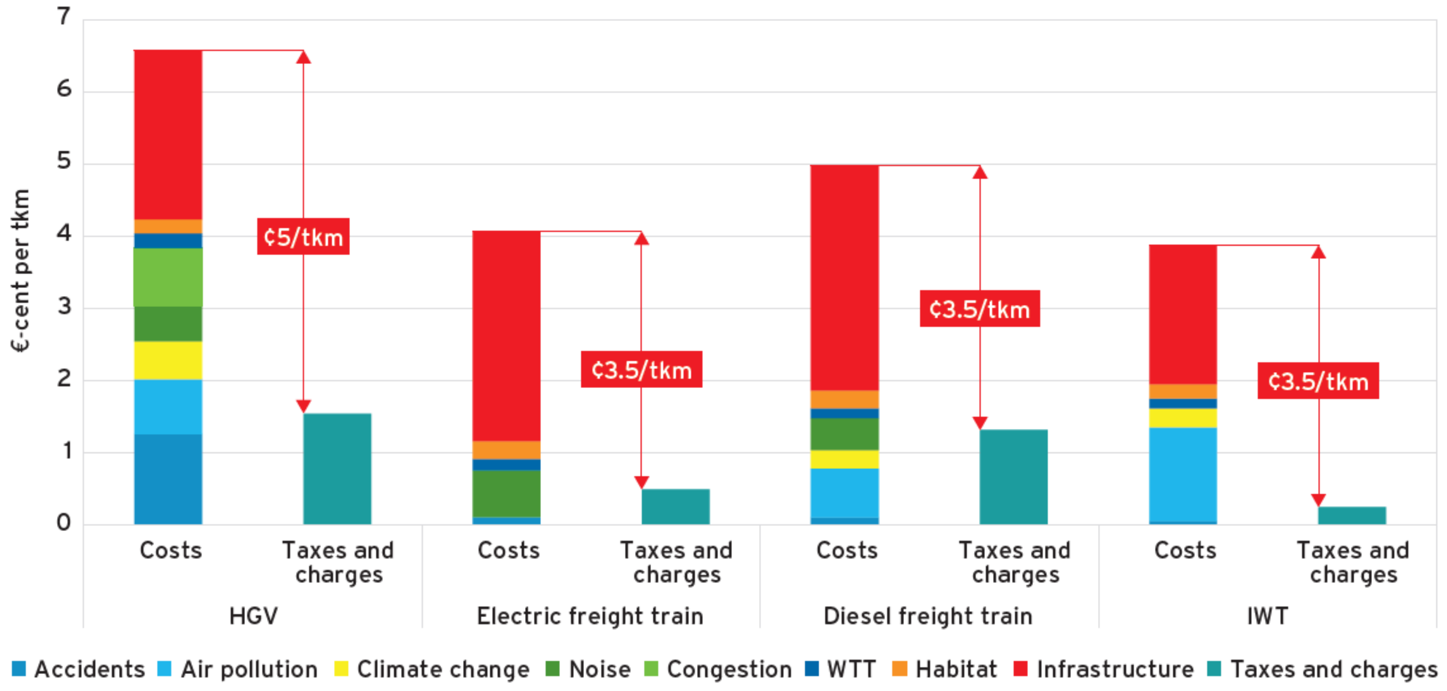
- **The energy- and labour efficiencies of combined transport when compared to the roughly 50% of unimodal truck transport that takes place on distances of 300km or longer amount to €70 billion as well as the €47 billion remuneration of 1,3 million full-time employees.**

  NOTE: assuming that the annual cost of employment of a full-time employee in truck transport is €36.000, the 1,3 million employees relieved by combined transport becoming the backbone of land transport saves €47 billion.

- **The graph indicates the external cots of various modes of transport as well as the taxes and charges that each are levied to compensate for these.**

  NOTE: the 1.000 billion tonne-kilometres of truck transport on distances of 300km or longer receives a 1,5 cent/tkm subsidy, which amounted to €15 billion annually in 2019.

COVERAGE OF AVERAGE COST - FREIGHT TRANSPORT MODES (PER TKM)



Source: updated European Commission Internalisation Handbook - CE Delft (2019)

SUMMARY: using the price levels of the 2019 edition of the CE Delft Transport Externality Handbook, the total uncovered efficiency advantage of shifting unimodal truck transports over 300km distances or longer to door-to-door combined transport stood at an annual €132 billion for the European economy. This amount is considerably higher if counting with present day prices.

Road Congestion and Combined Transport: how to prevent GDP loss?

- **The 2019 CE Delft Transport Externality Handbook put the congestion cost suffered by HGVs at €0,005 per tonne-kilometre, which on the estimated 1000 billion tonne kilometres performed by trucks on distances of 300km or longer amounted to €5 billion annually.**

  NOTE: the methodology for the congestion externality did not calculate with what portion of road congestion was caused by HGVs through accidents, where the HGV rate is 7-times compared to the proportion HGVs make up of the total road vehicle fleet of the European Union. Moreover, the severity of these accidents and their material consequences are also considerably greater. Also, the methodology did not calculate with the congestion caused by the accelerated wear and tear of the road infrastructure and thereby the increased maintenance and reconstruction works made necessary by the extensive circulation of HGVs.

- **The higher congestion causation factor of HGVs** – through accidents and accelerated maintenance and reconstruction needs – has yet to be scientifically calculated. The authors of this study estimate that (i) a 10% accident-related congestion reduction, while (ii) an 80% reduction in maintenance-related congestion reduction (due to the exponential wear-and-tear caused by the heavy axles of HGVs) can be achieved in case combined transport would become the backbone of longer-distance European freight transport on distances of 300km or longer.

  NOTE: studies available presently do not specify the proportion of road congestion attributable to accidents and road works, nevertheless the impact especially of the latter is well understood. A 2012 paper published by the European Union's Joint Research Center calculated the total annual cost of road congestion in the EU at €110 billion, which was equal to 1% of GDP at the time. Considering the EU's 2024 GDP estimated at €18 trillion, the figure is currently closer to €180 billion annually.

SUMMARY on road congestion: a substantial portion of the €180 billion annual cost of road congestion in the European Union can be attributed to the accidents and the road works attributable to wear-and-tear caused by HGVs. A potential 50% contribution would mean a yearly cost consequence of €90 billion (or 0,5% of EU GDP) impacting all road users.

European Modular System and Combined Transport: a efficiency-based comparison

EMS truck 25m/32m[1]	Efficiency category	combined transport
10-15% / 15-20%[2]	energy efficiency	**45-72%**
0%	infrasructure (road maintenance)	**50%**
50-100%	labour productvity[3]	**42-80%**[4]
n/a[5]	safety / accidents	**95%** (fewer)
10-20%	environment/climate	**65-91%**
0%	road congestion	**50%**

NOTES:

[1] EMS truck circulation is restricted to those sections of the road network that are capable of handling these increased dimension (longer and heavier) vehicles.

[2] Source: International Energy Agency

[3] Not taking into account the slower acceleration and deceleration of EMS trucks and assuming that EMS truck drivers are paid the same as drivers of regular trucks

[4] Besides requiring fewer manhours per tonne-kilometre, combined transport jobs offer superior work/life balance compared to a long-distance truck driver's which has not been factored in the comparison; moreover, the potentially higher salaries of EMS truck drivers compared to their compatriots driving conventional 18,75m long trucks, has also not been factored in the comparison.

[5] There is no data available; however in case EMS trucks reduce the number of HGV circulations (i.e. there are fewer trucks due to their introduction) then there may be somewhat fewer HGV-related accident occurrences, but the impact of a single accident will potentially be greater due to the increased size of the vehicle

The efficiency advantage, and therefore the contribution to Europe's competitiveness, is significantly better in case of a door-to-door combined transport operation than if using even a the longer 32-meter-long EMS truck combination weighing 60 or 70 tonnes.

Total efficiency perspective of long-distance freight transport in Europe in 2050

Scenario	**Modal shift** *of the 1000bn tkm unimodal road performance on 300km+ distances*	**Additional non-road / road-leg distances** *in bn tkm*	Number of additional intermodal freight trains per work-day	Annual growth rate 2025-2050	Results
Full performance	**100%**	**800** / 200	**4500** (200%↑)	8%	✓ 1,3 million fewer employees needed (€47bn/yr cost) ✓ €70bn less imported fossil fuels ✓ €85bn net savings for public budgets ✓ €90bn net congestion-related GDP loss saved
Intermediate	**65%**	**520** / 130	**2925** (130%↑)	6%	✓ 867 thousand fewer employees needed (€32 bn/yr) ✓ €47bn less imported fossil fuels ✓ €57bn net savings for public budgets ✓ €60bn net congestion-related GDP loss saved
Low impact	**35%**	**290** / 60	**1575** (70%↑)	4%	✓ 455 thousand fewer employees needed (€17 bn/yr) ✓ €25bn less imported fossil fuels ✓ €30bn net savings for public budgets ✓ €32bn net congestion-related GDP loss saved

Forecast impact:

→ For combined transport to become the backbone of longer distance land freight transport an average annual growth rate of 8% has to be achieved between 2025 and 2050.

→ A 6% annual average growth would reduce long distance unimodal trucking by two-thirds.

→ A 4% annual average growth would produce a one-third reduction in the performance of unimodal long distance trucking

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