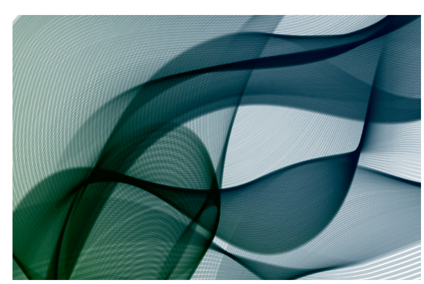
International Transport Forum

Towards Road Freight Decarbonisation

Trends, Measures and Policies



Decarbonising Transport

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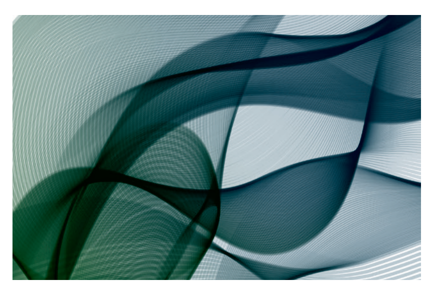

Decarbonising Transport

The International Transport Forum

The International Transport Forum is an intergovernmental organisation with 59 member countries. It acts as a think tank for transport policy and organises the Annual Summit of transport ministers. ITF is the only global body that covers all transport modes. The ITF is politically autonomous and administratively integrated with the OECD.

The ITF works for transport policies that improve peoples' lives. Our mission is to foster a deeper understanding of the role of transport in economic growth, environmental sustainability and social inclusion and to raise the public profile of transport policy.

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Executive summary

What we did

This report identifies proven measures that decrease road freight's CO_2 emissions. Goods transport by road consumes around 50% of all diesel fuel and accounts for 80% of the global net increase in diesel use since 2000. Projections see road freight activity at least doubling by 2050, offsetting efficiency gains and increasing road freight CO_2 emissions. The report highlights policy areas that need adjustment for effective decarbonisation of road freight and points to fields where more robust evidence is needed. It collects insights held at a workshop organised by the International Transport Forum in Paris in June 2018 and features the results of a survey of experts.

What we found

Decarbonising road freight has to move higher up on the decarbonising policy agenda. Estimates put road freight transport in first place for total energy consumption and emissions growth. Trucks are the fastest growing source of global oil demand, accounting for 40% of the oil demand growth by 2050 and 15% of the increase in global CO_2 emissions, according to baseline projections. Indeed, trucks will even surpass passenger cars as the major oil consumer sector. The available figures show not only road freight's current sizeable contribution towards CO_2 emissions, but its increasing relevance for the overall decarbonisation effort.

Road freight decarbonisation now requires implementing the easy-to-adopt measures that have already shown their efficacy in reducing emissions – low-tech solutions or already mature technology. However, achieving climate change targets will also require the widespread adoption of solutions that are not yet fully developed, whether in logistics or technology. Policy needs to evolve in order to create a favourable environment for the deployment of these solutions. It also must adjust to emerging trends that can further disrupt a sector that is already witnessing a transformation.

Improved and extended data collection is critical to designing and re-assessing these policies. The timing and exact configuration of road freight decarbonisation pathways should be adjusted to the different geographies and economies of each region around the world. Naturally, much of the discussion on the cost-benefit comparison of decarbonising alternatives – particularly on alternative fuel solutions for long-haul heavy trucks - is based on assumptions about future technological developments that are uncertain.

What we recommend

Broaden access to relevant data and improve their analytical uses for policies to decarbonise road freight transport

The importance of data for policies in support of decarbonising road freight transport cannot be over-estimated. Beyond emissions accounting, data are also essential for evaluating the impact of new and disruptive business models and the potential impacts of new vehicle technologies. Relevant data for properly estimating critical indicators exist in many countries, but they are mostly company-owned. Access to private data for public entities is thus important. Commercial interests and privacy concerns need to be properly taken into account. New modelling tools and more disaggregated approaches will help obtain additional insights for policy makers as well as the road freight industry.

Scale up tested and low-barrier decarbonisation measures for road freight transport

Technologies that improve the fuel efficiency of heavy goods vehicles are a fundamental component of decarbonising road freight. These include aerodynamic retrofits, reduced-rolling resistance of tyres, vehicle weight reduction, increased engine efficiency and hybridisation. Ambitious fuel economy and CO_2 emission standards will help widespread deployment of these measures. It is critical that these standards include heavy freight trucks. For urban freight operations, alternative fuels already provide a viable commercial solution, or shortly will. Policy should foster measures such as the adoption of alternative fuels for urban logistics operations through pricing mechanisms and other incentives, stricter emission standards, zero emissions zones, recharging infrastructure and policies geared towards adoption of alternative fuels by large fleets. Prime examples of low hanging fruit include eco-driving training and fewer restrictions on truck length and weight to maximise efficiencies from the introduction of high capacity vehicles (HCVs) on certain corridors. Further measures include the adoption of common standards for new equipment and processes, promoting off-peak deliveries, creation of collection points, route optimisation or voluntary emissions reduction programmes with set targets.

Seek ways to overcome regulatory barriers to collaboration in the logistics sector

Collaboration between logistics companies have the potential to generate significant cost savings and emissions reductions. So far, inter-company collaboration has taken place at an experimental level alone. Scaling up collaboration will be critical to unlocking the significant decarbonisation potential. Yet antitrust legislation sometimes hinders horizontal collaboration and legal risk has already prevented some trials. Digital collaboration platforms, operated by neutral trusted third parties, offer a promising pathway to overcome these barriers and offer the prospect of a pathway towards the "physical internet". Logistics firms should deploy new digital technologies in ways that allow them to enhance collaboration with other companies, with a view to deliver more efficient logistics services while complying with regulation and protecting their sensitive commercial information. Policy should support the sector in this effort.

Demonstrate the business case for investing in decarbonisation measures

Road freight is a commercial business operated by profit-driven private companies. In passenger transport, public bodies have a role including as service providers and trip choices are made by individuals. Logistics companies, however, have wide discretion over their operating mode and supply chains, and therefore need to play a leading role in decarbonising road freight. Firms have a self-interest in improving operational performance to cut costs. Fleet owners, shippers, retailers, hauliers and other stakeholder will only invest in these improvements, however, if the return rate, the payback periods and the risk level are attractive enough. In order to change behaviours in the industry it is necessary to make the business case for new logistical practices as well as pointing out their wider societal benefits.

In the mid to long-term, mainstream the use of alternative fuels with zero CO_2 emissions for road freight transport

Long-haul heavy trucks generate most of road freight's energy needs and CO_2 emissions. Yet the larger the vehicles and the longer their range, the more difficult it is to find cost-effective alternative, low- or zero-emission fuels. It is not foreseeable that zero-emissions propulsion for long-haul heavy freight trucks will come into widespread use in the short to medium term. However, such solutions need to be in general use by 2050 or earlier to reach agreed climate change targets. Direct supply of electric energy to the vehicle ("electric roads"), hydrogen and possibly electric batteries are currently foreseeable decarbonising technologies for heavy-duty long-haulage, although this assumes zero-carbon generation of electric power and hydrogen. It is unlikely that one single option can replace internal combustion engines. Even if electric roads can efficiently power long-haul road freight, they will not cover all trips. Hydrogen, electric batteries or advanced biofuels could complement them where electric road infrastructure is not in place. Strategic policy choices are likely required on the set of alternative fuels that will be scaled up. They will involve significant funding, especially for supply infrastructure. Scaling up solutions implies prioritising, yet some flexibility should be maintained over the short term. Trial and error is part of the prioritisation process, and further research and pilot projects should be encouraged. Breakthroughs in low-carbon liquid fuels, such as advanced biofuels or synthetic renewable fuels ("e-fuels"), or an acceleration in the deployment of carbon capture and sequestration (CCS) should not be ruled out, even if not foreseeable at present.

Tailor decarbonising pathways to the economic and geographical realities of different country groups

Given the different geographic, economic, regulatory and infrastructure conditions, a set of road freight decarbonisation strategies for each region is more suitable than a universal approach. In advanced countries, electric roads may become operational within a relatively short time-frame. For many developing countries, improving the quality of diesel fuel and renewing the fleets of old, mostly second-hand trucks to reduce "black carbon" emissions are among the immediate tasks. Increasing driver training and maintenance levels would also contribute to lowering emissions. In some regions, biofuels production may be close to carbon-neutral and cost-effective, but far from it in others.

Reader's Guide

The list bellow provides brief definitions of key concepts related to Road Freight Decarbonisation that were discussed in the workshop. These definitions were first drafted for the expert opinion survey to make sure that all respondents shared a similar understanding of the issues in question.

Alternative fuels

These are alternative propulsion systems to the traditional diesel (or petrol) internal combustion engine. This includes biofuels, synfuels or low carbon liquid fuels (mostly produced from agriculture crops or in some cases waste), natural gas that can be employed in liquid natural gas (LNG) or compressed natural gas (CNG) form. Gas can also come from waste like biomethane, hydrogen fuel cells (generates electricity), electric battery (fully electric or hybrid) and electric roads (electric powered vehicles where the energy source is external, e.g. by overhead catenary).

Collection points for customer deliveries

Having collection points per building, street or neighbourhood that are shared by different companies and accessible to customers for extended hours (one option is to have self-collecting points). Currently post offices are sometimes employed to this end - depending on the area there are also *ad hoc* arrangements with local shops. A more systematic and extended approach of this logic would imply collection points that are within short distance for customers, accessible for long hours and usable by different companies.

Countries, high-income:

Countries whose annual per capita income levels are higher than USD 12 000, such as Saudi Arabia, Japan, South Korea, Chile, France, USA, etc.

Countries, low-income:

Countries whose annual per capita income levels are less than USD 4 000, such as Angola, Georgia, Zimbabwe, Vietnam and Philippines, etc.

Countries, middle-income:

Countries whose annual per capita income levels are between USD 4 000 and USD 12 000, such as India, Russia, the People's Republic of China, Turkey, South Africa and Brazil, etc.

Crowdshipping

Deliveries performed by individual citizens, using their own means and organised by a digital platform. This is the logistics equivalent of the ride-sharing services for passengers ("peer-to-peer" for urban freight). There are already several online platforms providing these services and several big companies have developed pilot programs.

Digital freight matching

Digital platforms that match shipments with trucks, also referred to as online freight exchanges. These tools also offer a venue to digitalise the sector, streamlining the process, reducing paper and voice calls, tracking shipments and employing algorithms to increase operations efficiency (e.g. making it easier to find loads for empty returns). Conditions similar to crowdshipping are applied to regional and long-haul operations however the pool of potential service providers is narrower as there are higher requirements - the vehicles are more specialised and the drivers require specific training and certification. Currently there are new entrants and established companies developing these apps and services.

E-commerce

E-commerce has been steadily growing and is predicted to further increase. This trend has already affected the logistics sector introducing new entrants and changing service requirements.

Eco-driving

Driver training whereby drivers are trained to adopt a more fuel-efficient driving style.

High capacity vehicles

Describe vehicles with weights and/or dimensions outside what is permitted in conventional regulation. They generally involve a combination of tractor and trailers or truck and trailer. In Finland these vehicles can go up to 25.5 metres in length and 76 tonnes gross mass. In Australia there are double and triple road trains of 53.5 metres and 125 tonnes.

Intelligent Transport Systems

Advanced assisted driving systems (e.g. adaptive cruise control and real-time fuel consumption monitors that suggest modifications to driving behaviour).

Vehicle-to-vehicle communication systems can be used to set up semi-automated vehicle convoys. In these columns each vehicle follows closely behind the other in a centrally coordinated manner. This is also called truck platooning. To its maximum extent, intelligent systems combine a wide range of data and algorithms (e.g. sensor data, GPS, communication between vehicles and vehicles to infrastructure) can lead to fully digitalised autonomous trucks (or driverless trucks).

Modularised and standardised packaging units

Packaging that is modular combinable, stackable and standardised in terms of dimensions and functions. Currently, the 20 and 40 foot containers are the only units in widespread use. These new modular standardised units would be of smaller dimensions than containers and suitable for regional distribution and last-mile deliveries.

Operation type, long-haul:

Long distance transport (>100 km) performed mainly on motorways or other main roads. There is less breaking and manoeuvring. Generally involves heavier vehicles, such as large tractor-semi-trailer combinations. It accounts for most of the road freight volume or activity when measured in tonne-km.

Operation type, regional:

Regional distribution of goods (<100 km, typically 50-20 km) a sizeable part of which is done on local and regional roads. The vehicles employed tend to be medium sized, like rigid trucks, but there is great variability. The load factors and average speed tend to be lower than for long-haul. There is more braking and acceleration.

Operation type, urban:

Urban deliveries from local warehouses to retailers and customer deliveries. Mostly carried out on inner-city and suburban roads. Low average speed with frequent stops and starts. Vehicles tend to be lighter but there is great variability depending on the purpose. They represent a small portion of tonne-km, but a sizable amount of vehicle-km.

Optimisation of routing, assets and collaboration

Employment of digital-based optimisation tools for routing and scheduling of drivers and vehicles. Their aim is to strike an optimal balance between maximising the use of the driver's time and vehicle's loading capacity (weight and/or volume) and minimising distance travelled, fleet size and costs while satisfying service requirements. This can encompass GPS tracking for real-time routing which can be used to avoid traffic congestion. Collaboration and asset sharing between different companies, includes sharing digital networks, warehousing, loading and unloading facilities and space in vehicles. Sharing vehicle space could be particularly useful to maximise load factors of laden vehicles (favouring co-loading) and minimise empty runs (favouring backhauling). Additional benefits can come from joint optimisation of vehicles and depots.

Physical Internet

It is an open, shared global logistics system. It takes asset sharing and collaboration to its maximum potential. As a consequence, there are no longer individual logistics networks each operated by one transport service provider, but rather one global transport network using shared hubs. Competition between companies is focused on products not logistics and supply chains. Such a system would require new standardised modular packaging units, common protocol and tools, and shared logistics and digital assets.

Re-shoring

Move manufacturing closer to consumption centres. Reverse process of offshoring, where manufacturing is moved to another region where production costs are lower.

Shifts in trade routes

Opening up of new routes for trade generally associated with major infrastructure projects, e.g. One Belt One Road initiative or opening up the Artic for commercial shipping.

Vehicle efficiency

There is an array of vehicle technologies and improvements to vehicles that can reduce their fuel consumption. These include adaptations to existing vehicles to reduce aerodynamic resistance and rolling resistance, increased engine efficiency (e.g. engine friction reduction, waste heat recovery, optimising engine accessories energy use like air conditioning systems), weight reduction and improved transmission and driveline efficiency.

Widening delivery windows

Loads required to be delivered during a fixed time or very narrow time slot reduce planning flexibility and the ability to increase load factors. Widening the delivery windows facilitates better planning and maximising the resources used (including vehicle space).

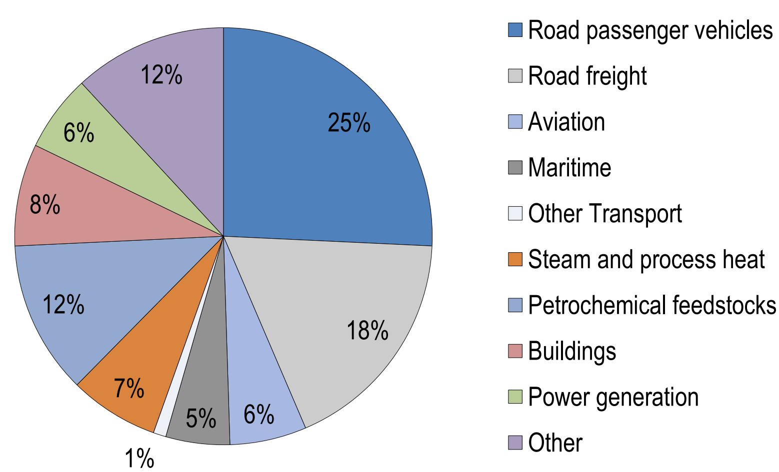
3D printing

Also referred to as additive manufacturing. A 3D printer is a computer-aided manufacturing device that builds a three-dimensional model out of a custom material.

Introduction

This report identifies proven measures that decrease road freight's CO_2 emissions. Goods transport by road consumes around 50% of all diesel fuel and accounts for 80% of the global net increase in diesel use since 2000. Projections see road freight activity at least doubling by 2050, offsetting efficiency gains and increasing road freight CO_2 emissions. The report highlights policy areas that need adjustment for effective decarbonisation of road freight and points to fields where more robust evidence through further research is needed. It collects insights discussed at a workshop organised by the International Transport Forum (ITF) in June 2018, in Paris and features the results of a survey among experts.

Figure 1. Sectoral consumption of oil in 2015 (mb/d, primary energy)



Source: Adapted from IEA (2017).

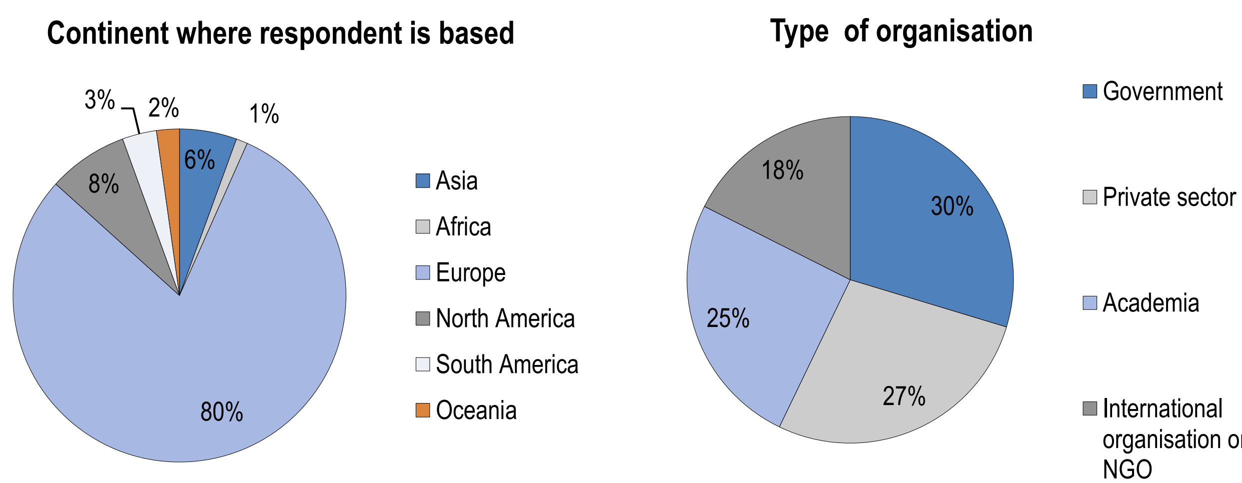
These initiatives are part of the ongoing Road Freight sectorial stream of work that is integrated in the wider ITF Decarbonising Transport (DT) project. The DT project aims to identify and promote policies which are both cost-effective in mitigating the climate change impact of road freight activities and which improve the sector's operational efficiency.

The main objectives of the workshop and survey were to gather initial evidence on the cost-effectiveness of different decarbonising measures and their policy implications. These included changes to logistics, alternative fuels and improvements to vehicle efficiency. Also explored were the impacts of intelligent systems, the role of infrastructure and how emerging market trends and disruptive technologies might shape the sector. The workshop was structured through eight sessions: pathways overview; logistics and supply chains; alternative fuels; vehicle efficiency; intelligent systems and eco-driving; the role of infrastructure; emerging trends and a review of policy implications.

The following questions guided discussions per session: Are the envisaged measures feasible? How much will they impact emissions? When, and with what adoption rate (timeline)? In which sectors (urban, regional, long-haul) and regions? Are they costly to implement and will they deliver high operational cost reductions? Finally, are there policy triggers that can foster the implementation of these measures?

The workshop was attended by more than 60 participants from different parts of the world, diverse backgrounds and with an interest in clean and sustainable road freight: government officials, energy companies, vehicle manufacturers, shippers, logistic suppliers, academia, research centers, professional organisations and representatives from international organisations. The presentations made at the workshop are available on-line (ITF, 2018a).

Figure 2. Survey respondents' background



The expert opinion survey was launched at the end of April, 2018 and answers were received until mid-June 2018. It was not open to the general public. Invitations were sent to experts and government officials that are part of ITF's Transport Management Board (TMB) and Transport Research Committee (TRC). In addition, invitations were also sent to the Corporate Partnership Board (CPB) and other DT partners. The questionnaire had 12 groups of questions and it took 15 to 20 minutes to complete. There were some specific questions for different measures, but they mostly focused on the same key questions discussed during the workshop: cost-effectiveness, expected market uptake and barriers to deployment.

In total there were 108 respondents. The majority were based in Europe (80%), but there were answers from all continents. Most respondents work for government organisations (30%), followed by the private sector (27%), academia and research institutes (25%) and international organisations or NGOs (18%).

The answers obtained reflect the opinions of a broad set of experts from different backgrounds. They provide insights into the likely impacts on CO_2 emissions, adoption timetables and costs of different decarbonising measures. They also help to identify what are the key barriers to implementation, most relevant policies to deploy and potential effects of emerging trends. In fact, the conclusions of the workshop and survey results will serve as inputs to the ITF modelling work on freight transport and inform the decarbonising scenarios that ITF is building. But, taken *per se* the survey replies do not provide an exact quantitative estimate of the impacts of different alternatives and policies. They are opinions and best judgements which have the potential to be biased.

This report's structure follows the workshop's outline where the presentations and discussions for each session are summarised in the respective sections of this document. Results from the survey are shown by topic in conjunction with the workshop sessions. Key takeaways and recommendations are discussed at the end of the report. The presentation summaries provide useful context and background to the discussion, but they do not necessarily reflect ITF's views or an endorsement to options proposed there.

Box 1. International Transport Forum Decarbonising Transport initiative

In December 2015, 179 governments signed the United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement on Climate Change, out of which 162 had submitted Intended Nationally Determined Contributions (INDCs). This process created a political pathway for climate change mitigation efforts by setting up a five-year review cycle for national decarbonisation commitments starting in 2020. The International Transport Forum (ITF) Decarbonising Transport (DT) initiative will track global progress towards decarbonisation of transport and help governments close the gap between their commitments and mitigation actions, by guiding them towards establishing commonly acceptable pathways to reduce transport carbon dioxide (CO_2) emissions, in line with the aspirations of the Paris agreement. The first cycle of the project runs to 2020.

The initiative is non-prescriptive: it does not advocate specific measures or policy packages but offers decision-makers the tools for selecting the CO_2 reduction measures that deliver on their strategic objectives by providing the best possible assessment of the impact of given mitigation policies.

The initiative is also inclusive in that it engages with stakeholders across the transport sector, organising, for instance workshops both at technical and political levels. This approach is based on recognition of the large scale of the challenges and on the need to mobilise the capacities and resources of many sectors and organisations globally to tackle them successfully.

The project outputs are set out to prepare the transport sector for the climate negotiation process in 2020 and advance the decarbonisation of transport systems. The initiative will contribute to international co-operation by supporting the implementation of the decisions and resolutions of the UNFCCC through various dissemination and communication tools.

The ITF Decarbonising project has three main objectives:

a. Gather evidence and best practice for decarbonising transport through continuous engagement with countries and partners.

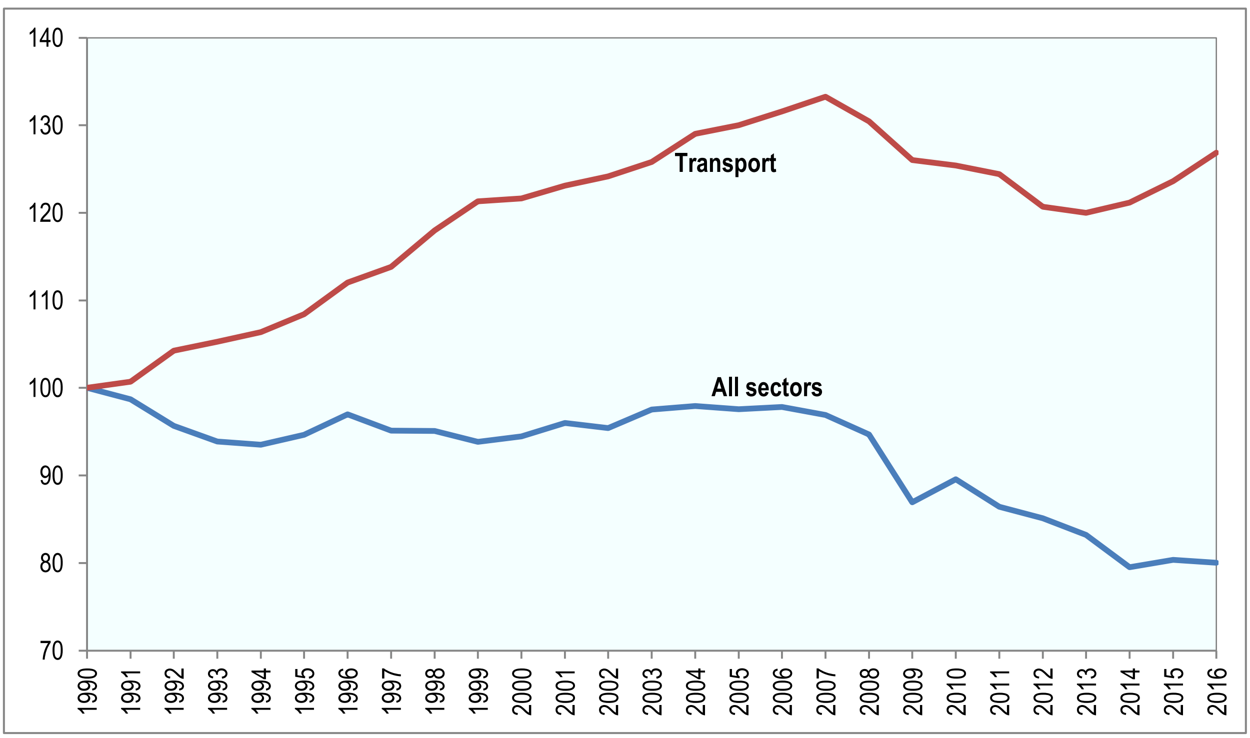
b. Help countries design robust transport and climate policies by developing and disseminating a catalogue of mitigation measures with quantitative evidence of their effectiveness, including assessment of confidence in the results.

c. Increase understanding and build capacity in countries and partner organisations regarding ways to mitigate carbon emissions from transport activity.

Pathways overview

Transport accounted for 22% of the total global energy-related CO_2 emissions (7.8 Gt of CO_2) in 2015. It is one of the main sectors responsible for current emissions. Moreover, as other sectors –mainly energy production - reduce their carbon intensity Transportation is still dependent on fossil fuels - namely oil derivatives like diesel and gasoline. The numbers for the European Union (EU) illustrate this trend in a clear way. Whereas the total emissions have been decreasing and were cut by 20% from 1990 to 2016, the transport related emissions actually increased in the same period by 27%.

Figure 3. CO_2 emissions trend, EU-28, 1990-2016 (Index 1990=100)

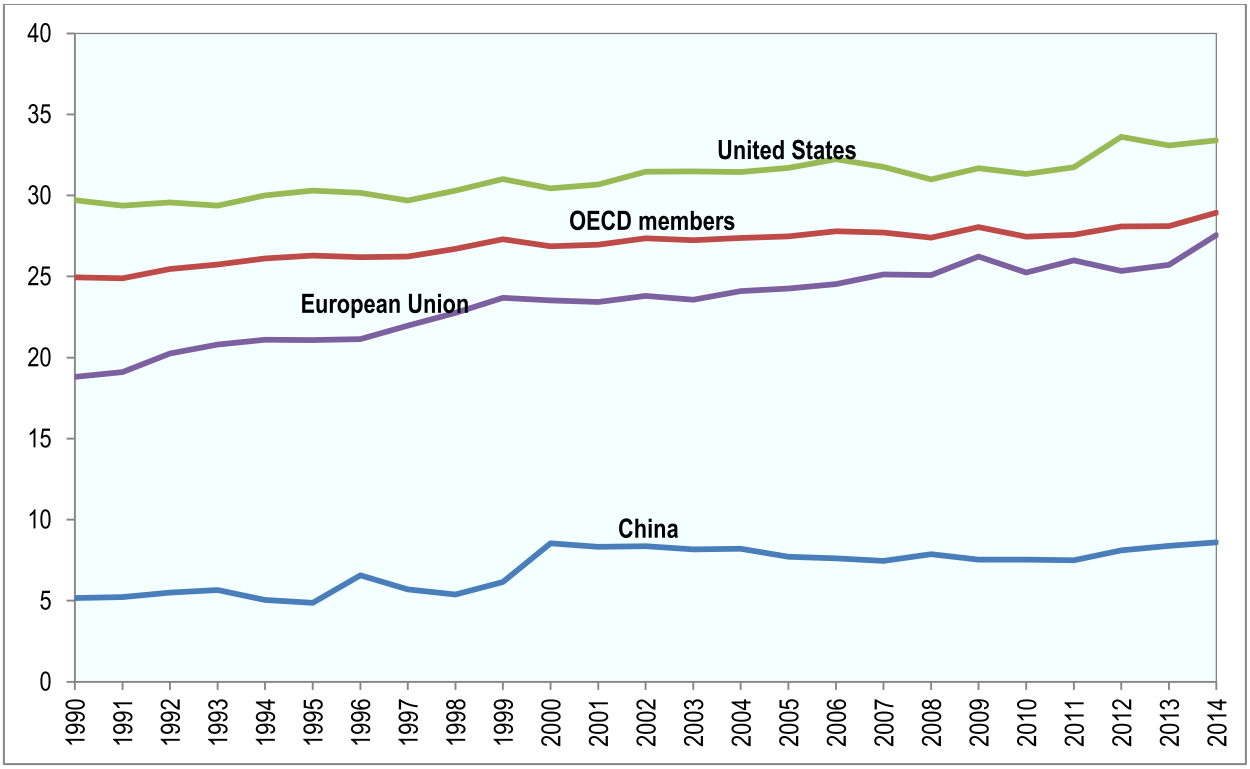


Source: based on European Environment Agency (EEA) (n.d).

This disparity is noticeable for the group of OECD countries and emerging economies like the People's Republic of China where the share of transport related emissions out of the total emissions has been trending upwards. Road freight is a major consumer of energy - most of it coming from oil-based fuels – and emitter of CO_2. It is predicted to increase in activity and therefore its relevance towards the overall decarbonisation effort.

As other sectors slow their emissions growth and even decrease them due to effective measures and strong policy commitments (e.g. increase in energy generation from renewables and gas, decrease in coal based production) this has not happened to the same extent in the transport sector, particularly for Road freight. While more than 80% of the light duty vehicles (LDV) market is covered by fuel economy standards, only four countries (Canada, China, Japan and the United States) currently have these standards for trucks covering 51% of the market (the EU is expected to adopt them soon). Historically there has been lower pressure on the policy side for trucks than for light duty vehicles.

Figure 4. CO_2 emissions from transport (% of total fuel combustion)



Source: based on The World Bank (n.d.)

There are straightforward reasons that explain why the sector is lagging in decarbonising efforts compared to other activities. For one it could be argued that decarbonising energy production is a more upstream effort, almost a pre-requisite to decarbonise the sector. In fact, electrification of road transport either through batteries, hydrogen or directly powered through the infrastructure will only meaningfully decrease emissions if the electric energy used to power the vehicles (or batteries, or hydrogen generation) is itself carbon free or produced from a decreasingly carbon intensive mix.

Importantly, there is no reason why these efforts should not take place in parallel. They can even be mutually supportive with the transport sector absorbing unused excess renewable energy. Given the global estimates of further growth in activity - tonne-kilometres (tkm) - simply maintaining current emission levels will require increased emphasis on policies and measures directed at decarbonising road freight (ITF, 2017a). To that end, some potential “low hanging-fruits” were immediately identified in the workshop opening session. Eco-driving, driver training for fuel efficiency is one of the most cost effective ways to reduce emissions. For urban type operations on light commercial vehicles alternative fuels – namely electric batteries - are a feasible option and even advantageous in some situations from a business point of view. Relaxing restrictions on truck length and/or weight and heavy capacity vehicles (HCV) is already in operation in some OECD countries like Finland or Australia (with some restrictions on the routes where they can be employed, e.g. in Finland they cannot use certain designated bridges). Limiting HCVs to certain origin-destination (OD) commodity pairs where there are no alternative heavy modes can offer a pathway for more widespread use. Improve data collection and indicators of logistical activities in order to better assess impacts of measures designed to improve capacity utilisation. These should take into account measures of volume, weight and floor space. Expand coverage of fuel economy standards for heavy freight trucks vehicles and increase adoption of vehicle efficiency technologies (e.g. aerodynamic, reduced-rolling resistance for tyres, weight reduction and increased engine efficiency).

In addition to these options that can and should be implemented immediately there are overall insights to be taken into account when designing policies aimed at decarbonising the sector. First, decarbonising road freight has to move higher in the overall decarbonising policy agenda. Second, Road freight is mostly a private and profit-driven sector. This is different than what occurs for passenger transport and urban mobility, where government and other public bodies play a more direct role and which historically have deserved much more policy attention. Setting up policies requires recognising that companies will play a key role since they are the ones that directly control their operations and set up their own supply chains. It will be extremely hard - if not outright impossible – to achieve decarbonisation goals if the respective policies do not take into account the private interests of shippers, logistical suppliers, transport operators and other companies involved in the business.

Different regions require different pathways and strategies for decarbonising. In some developing countries the widespread use of second-hand vehicles is a matter of key concern. Reducing the fleet age and increasing the efficiency of their use would deliver great benefits. The introduction of newer and larger vehicles (e.g. standard heavy truck sizes from Europe or the United States) per se would have a significant impact. This is associated with improvements to diesel quality and reduction of "black carbon" emissions (Miller and Jin, 2018).

Deep decarbonisation of long-haul, heavy trucks will require the employment of alternative fuels. For this operation type there is not yet a clear, mature solution as there is for urban type operations. Further research and demonstration projects are required to find feasible solutions from an operational, economic and emissions point of view. These solutions might vary for different regions and availability of sustainable alternative fuels, e.g. advanced biofuels might be close to carbon neutral in some markets but far from it for others. Nonetheless, given current knowledge the technologies that look more promising and scalable are hydrogen, the direct supply of electricity (or electric roads) and possibly electric batteries.

Presentation summaries

Truck emission scenarios

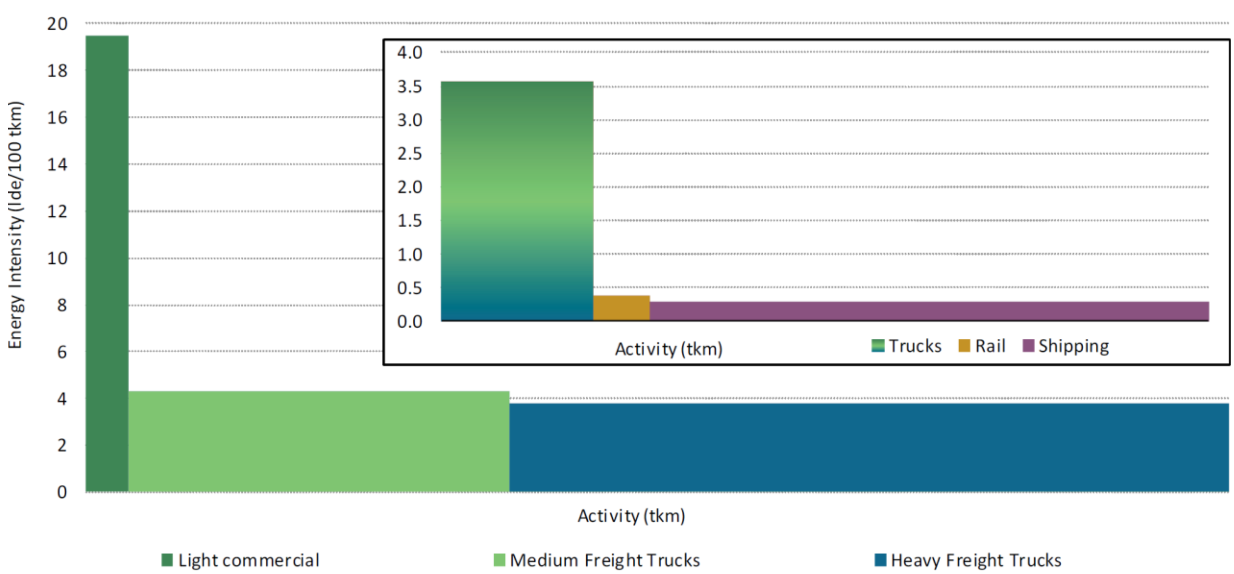
Road freight transport has a critical role in the movement of goods which makes it a key sector for the global economy. Given its strategic importance the International Energy Agency (IEA) recently issued a report (IEA, 2017) looking at the role trucks play in energy consumption and emissions. The document has two major components, the first assessing the current state of the sector and a second forward looking exercise that explored different "what if" scenarios.

As a starting point for the estimation of current energy use and emissions of the Road Freight sector the IEA looked into the global vehicle stock. Three generic types of vehicles were considered: Light Commercial Vehicles (LCVs), Medium Freight Trucks (MFTs) and Heavy Freight Trucks (HFTs). There are strong differences in the mix of vehicles across the world, for instance in more developed countries the shares of MFTs tend to be lower than in developing countries while the proportion of LCVs and HFTs tends to be higher. A second building-block in this analysis is the mileage (km per year) for each type of vehicle, which also varies for different regions. On average HFTs travel the most km per year, MFT and LCVs come in second and have the fewest amount of km.

Another key element in this analysis is determining the loads per vehicle. This is a topic known to have data accuracy challenges and simplified assumptions were used in the IEA's models. There are a host of factors that influence the size/load capacity and the average used loads, but the IEA studies indicate that there is a decline in loads with income growth (GDP per capita) for MFTs which can be explained by the more intensive use of these type of vehicles in lower income countries. The opposite happens for the HFTs whose load capacity increases with income. Indeed, more developed countries can have better infrastructure that allows for larger-heavier trucks, more available capital to renew fleets and have more modern and specialised vehicles (e.g. have more tractor-trailers and combination trucks). These trends refer to average values that include all vehicles in a given category across regions of the world, not specific situations that might occur in a particular place or industrial sector. For instance, the heaviest trucks in South Africa tend to have a gross weight (loaded) of 57 tonnes, which is considerably higher than for Europe.

Assessing fuel economies - i.e. the amount of fuel consumed on average per km for the different vehicle categories in different markets - is the last component in the analysis to the current impact of trucks. The average payload is an important parameter driving fuel efficiency per tonne-kilometre (tkm).

Figure 5. Energy consumption of road freight sector



Source: IEA (2017).

When all of these elements are combined - vehicle stock, mileage, payload and fuel economies – it is possible to estimate the global energy consumption of this sector. In Figure 5 the x axis corresponds to activity (tkm) and y axis to energy intensity (litres of diesel equivalentper100 km), hence the areas in the graphs are the total energy use. These estimates highlight why this is such a relevant sector regarding energy use and in any efforts to reduce emissions. According to IEA figures it accounts for 20% of all freight activity (tkm), but it consumes more than 70% of the energy used to move goods. In fact, at around 17 million barrels per day (mb/d) road freight transport is the second largest user of oil after passenger cars (see Figure 1). The sector is also responsible for nearly 40% of the oil demand growth since 2000. Most of the energy used by the sector is for HFTs, followed by the MFTs and lastly the LCVs.

But LCVs have by far the highest energy intensity, being the least energy efficient. This of course has much to do with their role in the logistical chain. LCVs are mostly used on the “last-mile” in urban environments and they are smaller vehicles. Furthermore, many of the LCVs are not actually used for moving goods, but by craftsman and other small businesses hence not carrying full loads most of the time. This will lead to lower average loads and energy efficiency per tkm.

Global increase of energy use and emission in this sector has been driven in recent years by growth in China, Latin America, the Middle East, India and other rapidly developing economies. Currently China’s emissions are roughly equal to that of the European Union (EU28).

Having examined the current impacts of trucks the second main component of the IEA report is to project future energy needs for the sector under two key scenarios – a Reference Scenario and the Modern Truck Scenario. In the Reference Scenario, vehicle stock structure and mileages broadly reflect historical development. Vehicle technology development does not factor in major changes and there is no steep increase in the policy pressure. Under these conditions the IEA forecasts a 50% growth in energy use from road freight by 2060. This growth is driven by countries outside the OECD, e.g. India is projected to catch up with China by 2035 and accounts for as much as North America in 2060.

According to this projection trucks are the fastest growing source of global oil demand accounting for 40% of the oil demand growth to 2050 and 15% of the increase in global CO_2 emissions. Indeed, trucks will even surpass passenger cars as the major oil consumer sector. Road Freight transport is the number one sector in energy consumption and emissions increase.

Given these forecasts there is a strong argument to be made for stronger measures and the need for policy instruments to curtail this growth. The IEA Modern Truck scenario proposes a more ambitious vision supported by three pillars:

- Vehicle efficiency (contributes to 34% of the fuel savings).
- Systemic improvements in logistics (contributes 42% of the fuel savings).
- Increased uptake of alternative fuels (contributes 24% of the fuel savings).

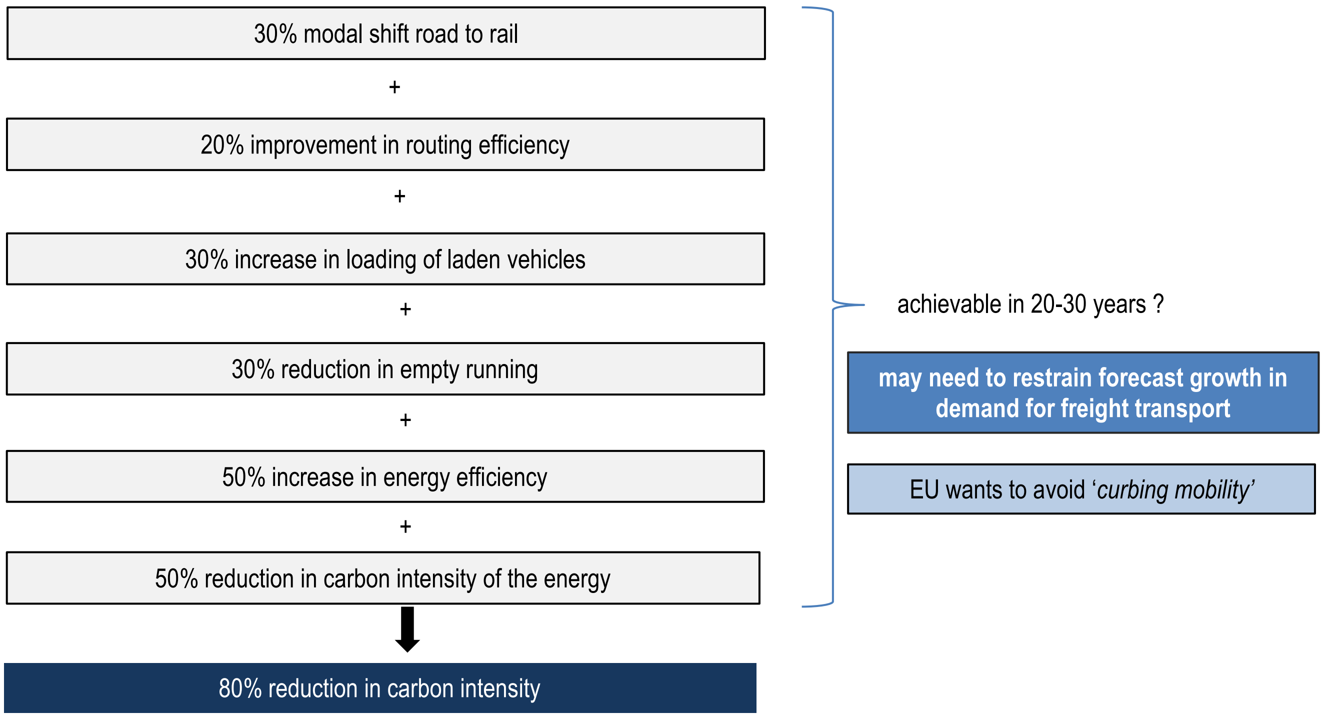
Adoption of such measures could lead to a very different future for trucks. Oil demand would be 50% lower (13.5 mb/d) than in the reference scenario. Emissions could decrease by 75% (2.5 Gt). This would be sufficient to be in line with the temperature targets of the Paris Agreement.

A review of the technical, operational and managerial options

This presentation provided a broad overview of the current state of knowledge on the available options to decarbonise the sector and their respective caveats, much of it based on research done by McKinnon (2018). The review provided can be encapsulated in four words: Urgency, Scope, Uncertainty and Transferability.

There is a need to convey a new sense of urgency in the logistics sector. On the climate side the Intergovernmental Panel on Climate Change (IPCC) recently released a report emphasising the importance of staying within a 1.5 °C scenario. This would mean that at the current level of emissions the carbon budget will be depleted in 18 years. Thus the emissions peak should be reached fairly quickly and start to drop after that. This applies to the overall global emissions, of which road freight is a relevant part.

Figure 6. Leveraging freight decarbonisation parameters to achieve 80% reduction in carbon intensity



Source: McKinnon (2018)

The sector is not fully aware of how urgently it is necessary to reduce emissions. The prevailing mind-set is still that emissions will have to be reduced at an annual level, at some future date during the next 20-30 years by a certain amount when it is the cumulative emissions from road freight transport that are a significant driver of climate change. But the challenge is much more immediate. Focusing on Europe, the 2011 EU commission white paper (European Comission, 2011) set an objective to reduce at least 60% of greenhouse gas (GHG) emissions in the transport sector (passengers and freight) by 2050 with respect to 1990 levels. Just for the freight sector this means an 80% reduction in carbon intensity (CO_2 per tonne-km) between 2015 and 2050 for all modes. The efforts required across several parameters to reach that goal for surface freight are displayed in Figure 6. It might not be possible to reach this ambitious EU target for reducing carbon intensity without curbing demand growth. But the latter runs against EU thinking that does not want to limit mobility. The overall drive for ever growing economic activity is one of the main - if not the main - goals of any country or society.

To actually achieve the end goal and do it with an emissions profile where reductions start happening in the short term it is really key to act on "quick wins" or "low hanging fruits". There are some measures that can have high impacts but which can only be achieved far into the future (2040-50?), e.g. the "Physical internet". But there are several measures that can be implemented now and quickly start to deliver savings. Achieving the targets also involves road mapping, e.g. (IDDR, Sustainable Development Solutions Network, 2015). It is difficult to obtain the data to produce accurate estimates on the impacts of all the measures and their interactions, but nonetheless these estimates are relevant to set up pathways towards decarbonising.

Relaxing truck regulations by raising the limits for weight and size could provide quick direct emission cuts. According to this presentation there is hard evidence that this could be an effective decarbonising measure. One of the solutions proposed in Europe would be able to replace three current trucks by only two high capacity vehicles, this corresponds to a 33% decrease in the number of vehicle-km required to move the same tonne-km (for the particular market segments where this substitution would take place). Such substitution would lead to less energy consumption and emissions. It is estimated that this could reduce the carbon intensity (CO_2 per tonne-km) by around 20%. This would however run against other key pillars of decarbonisation, namely modal shift.

When scoping the methods available to decarbonise it is possible to group them in five major categories according to the type of parameters or drivers of emissions they act on. It is possible to have methods that: reduce the level of freight movement; shift freight to lower carbon modes; improve vehicle loading; increase energy efficiency; switch to low carbon energy. The first three types of actions are in the fields of logistics, management, behaviour and regulation. The last two methods are related to technology and engineering. There are high levels of uncertainty about the potential contribution that these five sets of methods can make to decarbonisation. All of them are discussed throughout this report.

Much of the thinking and research on decarbonising relates to OECD countries and the developed world. But solutions that suit these countries might not be directly transferable to emerging economies and these are exactly the places where most of the forecasted growth for road freight transport will take place (ITF, 2017a). Simply looking at the average age of the truck fleet or the emission standards in place and it is quite clear there is a huge gulf between these two parts of the world - with much lower standards and higher vehicle average ages in developing countries. In fact, taking a global perspective requires discussing the overall supply chain for second hand vehicles. Many used trucks in the developed world are sold to the developing world where they spend the rest of their life-cycle. Due to a lack of engineers, qualified staff, spare parts and other issues (e.g. infrastructure supply quality) the vehicles operate at lower performances and higher energy consumption than might otherwise be the case.

Issues outside the sector itself also need also to be taken into account. In many emerging markets carbon intensity of electricity production is high and only slowly declining, which will hinder any benefits from the shift to electric vehicles. The ability to finance infrastructure is also an issue. If highway electrification is adopted as a main alternative for heavy trucks will there be enough resources to invest in upgrading the highway system? The same holds true for distribution and recharging facilities in case other alternative fuel technologies are adopted.

Discussion

There are areas that can have a fundamental impact in the ability to curtail emissions but are fairly contentious topics where debate is far from settled. For instance: limiting demand, decelerating logistics, HCVs or modal shift. Demand growth is the number one driver for increased emissions; it is not at all evident if it is possible to decrease emissions in a meaningful way if current volume (tkm) forecasts are not averted. Advocating for restraining growth as a possible policy instrument can be seen as a biased proposition, particularly from a developing world point of view. These are the regions where most of the demand increase will actually take place, but where income levels and living standards are still far below OECD levels – e.g. India currently has around 20 private cars per 1 000 inhabitants (ITF, 2017a) while the EU average is 505 (Eurostat, 2016a) - hence the imperative to grow is central to their economic and political landscape. Moreover, this is not only an issue in developing countries. In the EU 2011 White paper that sets ambitious reduction targets it is also stated that “curbing mobility is not an option”. A wider discussion related with this topic is the employment of GDP as the cornerstone indicator to measure development. It can be argued that many aspects of well-being are not measured by GDP, hence the need to revise its calculation or complement it with other indicators.

Simply avoiding transport is indeed one of the most obvious options to decarbonise and the fact is there might be economic, political and behavioural trends that curb demand for transportation. Digitisation, when material goods are substituted by digital exchange of information is an example of reducing the amount of tonnes moved (e.g. when CDs, books or newspapers are substituted by their digital versions). The growth of sharing economy can also contribute to this by a more intensive shared-use of available assets with less need to manufacture new products (e.g. cars and other vehicles). Circular economy also aims at curbing the need for new products replacing the "take, make and dispose" mode of production by more long-lasting designs with renewed emphasis on maintenance, repair, reuse/refurbishment and recycling.

Other initiatives focus more on the decrease of distances than the products itself. For instance, re-localisation, decentralisation and re-shoring along with 3D printing can decrease the distances between production and consumption centres; reducing the km's necessary in today's long and complex supply chains. There is great uncertainty surrounding the extent to which re-shoring and 3D printing will dampen the future growth of road freight transport. According to the ITF opinion survey these were some of the least likely trends to take place (see Figure 35). But the same survey also showed that they could decrease distances (see Figure 39), thus road freight volumes (tkm). Other sources and surveys – see Disruptive Technologies section of the Emerging Trends chapter – indicate a higher potential uptake for 3D printing. In addition, since the 2008 crisis there was a decrease in the elasticity of global trade to GDP (ITF, 2017a). This has happened at the same time there are rising trade disputes and protectionist measures (OECD, 2018; WTO, 2018 and UNCTAD, 2018). These are developments that might affect the global transport of goods, although other modes (e.g. Air and Sea) will likely be more affected by a curb on international freight movements than road.

Behavioural changes might also play a role. In developed countries, particularly after the 2008 crisis, there is a trend to value and spend more on experiences (e.g. travelling, eating out), than on material goods (e.g. furniture or clothes). Data from the United States on the evolution of retail sales by sector seems to point in that direction where the three top growing sectors are respectively: Nonstore retailers (e-commerce); food services and drinking places and health and personal care stores (Federal Reserve Bank of St. Louis, 2018). Still, the largest growth is by far in the Nonstore retailers group which grew almost four times as much as the other sectors combined. So, there is indeed a trend to spend more on experiences but even more impressive is the rise in e-commerce.

Decelerating logistics and relaxing "just in time" (JIT) can decrease emissions by reducing the speed of vehicles and allowing for consolidation and improved payload capacity use (McKinnon, 2016). There is literature indicating that short delivery windows and the market push for higher service levels hinders efforts to increase capacity use, e.g. (Route Monkey and WBCSD, 2016; Transport and Mobility Leuven, 2017). In the ITF survey there was an almost even split in opinions (see Figure 11). Regardless of its potential impacts decelerating logistics goes against market trends and it is anathema for the industry. Moreover, the JIT paradigm minimises waste in other parts of the production chain and contributes to less energy and CO_2 emissions in other sectors.

But decreasing vehicle speeds alone will not necessarily affect delivery times (time savings can be made through non-transport activities of the logistical chain). For safety reasons Japan has lowered the speed limit for trucks which brought other benefits like a 10% decrease in operational costs and emission reduction due to lower fuel consumption. In fact, slow steaming is a common operating feature of today's shipping industry with cargo ships moving at significantly slower than their maximum speed. This is a very cost-effective way to decrease GHG emissions. As a rule of thumb they can be 19% per voyage for a 10% reduction in speed, but can go up to 60% (ITF, 2018b). For road freight a heavy truck speed decrease on a highway from 90km/h to 70 km/h can lead to fuel savings of 12% (AEA and RICARDO, 2011).

Modal shift from road to less carbon intensive modes such as barges and rail is another long-debated option. Indeed, road freight nowadays has on average much higher energy intensity than other surface modes (see Figure 5). However, road offers a level of flexibility, accessibility and overall service level at competitive costs that make pure modal shift difficult.

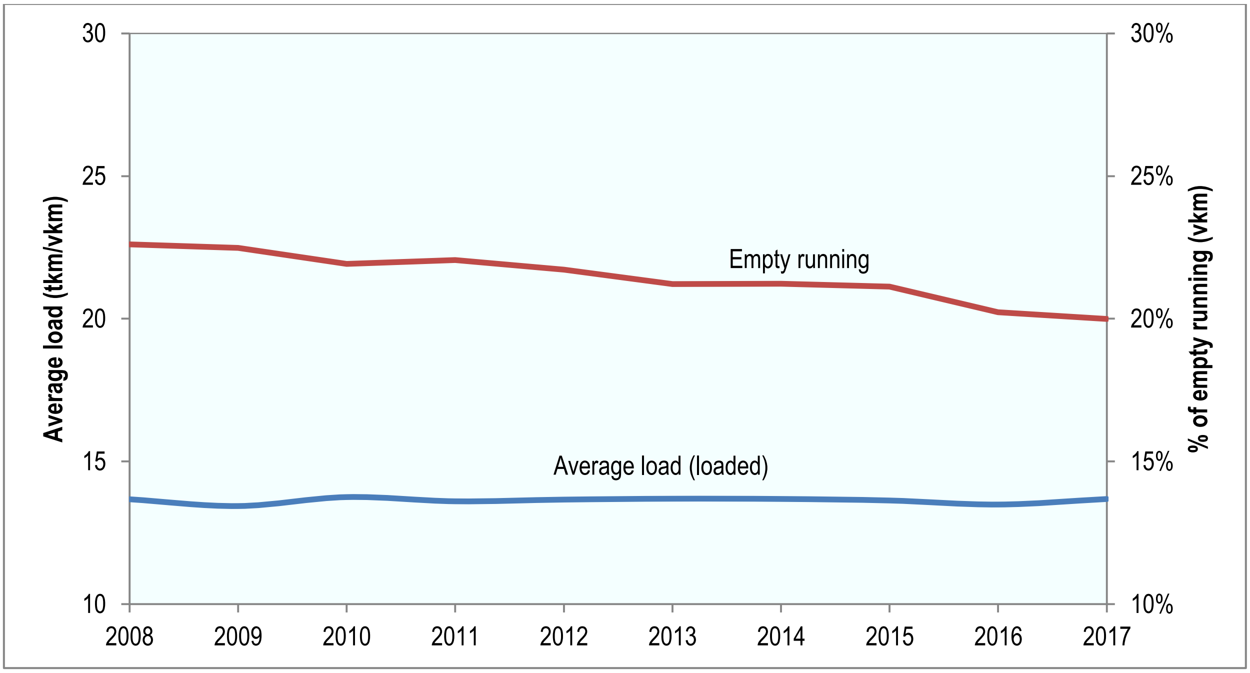
In Europe the results have been far from expectations and there are several structural reasons for this (Crozet and Woodburn, 2014). The target defined in the EU 2011 white paper was to shift 30% of road freight activity over 300 km distances to rail and inland waterways by 2030 and 50% by 2050. According to (Tavasszy and Meijeren, 2011) achieving the 2030 target would mean that the overall rail share would be close to 40% and road just above 50%. This implies that in less than 15 years rail would have to double its current share. Is that really likely? Particularly taking into consideration that demand for some core commodities nowadays moved by rail – heavy bulk materials such as coal and other fossil fuels – will more than likely decrease. In this situation it will be a challenge in itself for rail to keep its current mode share. Nonetheless, in other regions with longer distances, less coastline and ports density, more concentrated transport corridors (e.g. India, China, South Africa) modal shift might be an option with greater potential than Europe. In addition, with increased vehicle efficiency and adoption of alternative fuels there can be a narrowing of the carbon intensity gap between long-haul road and rail freight. Although this gap still remains wide, according to (IEA, 2017), on average the energy intensity of heavy freight trucks is more than eight times higher than rail (this gap is shorter when the comparison is made considering more advanced long articulated trucks which are three to five times more energy intensive then rail).

An extensive review of the literature in (McKinnon, 2018) points to a tendency to increasingly favour options on the technological and engineering side over softer managerial or operational measures. There is likely an under-estimation of the potential logistical contribution to road freight decarbonisation.

One of the reasons for this trend can simply be academic bias in this field towards physical science and technological solutions versus social sciences and more organisational type changes. A second cause is related to the difficulty in quantifying carbon savings from logistical options. There is great uncertainty about baseline conditions (mentioned in the IEA presentation) and the rate of behavioural change in the sector. Moreover, there is lack of macro-level data for critical indicators to evaluate potential improvements in the sector such as loading and capacity utilisation. At the EU level - which has a more developed data collection compared to other regions - there is indeed some data on empty running and average payload weight. But having data on average load is not that useful to measure capacity utilisation without knowing the respective average capacity of the vehicles. Some countries in the EU like the United Kingdom do provide figures for weight utilisation – the European Environment Agency (EEA) published some reports collecting these figures for several countries, even though their most recent numbers are for 2008 (EEA, 2010). But regarding volume (or floor space) use there are no available records. This makes it almost impossible to have estimates on the extension to which improved loading can cut carbon emissions since it is unknown to what degree volume and space are currently being used.

Increased focus on technical solutions over logistical measures also has to do with discouraging past experiences. For instance, empty running in the EU over the last ten years only dropped slightly. Over the same period there has been an increase in online load matching (or Digital Freight Matching), relaxation of cabotage regulations and a growth of reverse logistics. These developments should have pushed empty running numbers further down but that has not happened. Supply chain collaboration is also acknowledged for its great potential – having companies share their assets, decreasing their costs plus energy consumption and cutting emissions. Nonetheless, after 30 years of debate this is still the exception rather than the norm. There are some anecdotal experiments, but no widespread adoption.

Figure 7. EU Average load of loaded vehicles and empty running



Source: based on Eurostat (2016b)

Uncertainty in the potential of decarbonising initiatives is not confined to the logistics field. There are conflicting accounts on the past record of fuel efficiency improvements for European trucks. Several institutions like the International Council on Clean Transportation (ICCT) (Muncrief and Sharpe, 2015) and Transport & Environment (Transport & Environment, 2016b) argue that there has been a stagnation on fuel efficiency improvements over the last 20 years (although great improvements were made in reducing air pollutants). But the manufacturer Daimler claims that there has been a significant improvement in fuel efficiency with a reduction of 15%-20% of fuel consumption per 100km (Daimler, 2016). It is quite challenging to estimate the impact of future improvements, when there is no agreement on past record (Transport & Environment, 2016a).

The feasibility of powering heavy freight trucks with electric batteries is also a topic open to contentious debate. Recent McKinsey reports and the seminal paper (Sripad and Viswanathan, 2017) argue that a United States class 8 truck (assuming a 36 tonnes gross vehicle weight) for long range operations would require a 12 tonne battery or more, which would severely encroach on the available payload of the trucks. Meanwhile, Tesla states that with a battery of 4-6 tonnes it is possible to achieve the same performance and a range above 450 km, something contested by this study and others (Lambert, 2018). Moreover, at 1 600 kW per hour, the charging times would be four times faster than former studies that indicated around 400 kW per hour, which itself is currently considered as extremely fast charging (Howell et al., 2017).

A further example is the discussion on Hydrogen as a viable alternative fuel for this sector. There is a body of opinion exemplified by the Institute for Sustainable Development and International Relations (IDDRI) and UCL Energy Institute that envision Hydrogen as the dominant pathway for decarbonising long distance heavy road freight transport in the United Kingdom by 2050 (IDDR, Sustainable Development Solutions Network, 2015). Some in the industry are supporting this alternative - recently Anheuser-Busch placed an order for 800 hydrogen-powered trucks (Reuters, 2018). Others like Bossel (Bossel, 2006) and Cebon (Cebon, 2018) argue that due to the energy losses along the supply chain hydrogen is a costly and prohibitively inefficient way to use available electric energy. These concerns are echoed in research commissioned by the German Ministry of Environment (Kasten, Mottschall, Köppel, and Degünther, 2016). The debate on pathways to decarbonise is not fully settled and a division of opinions remain on fundamental aspects. In the next chapters of this report we will go more in-depth into several of these issues.

The scheme in Figure 8 provides a summary of tested measures (or “low hanging fruits”), fundamental areas surrounded by contention and uncertainty, plus insights for designing policies to decarbonise the sector discussed in the opening session.

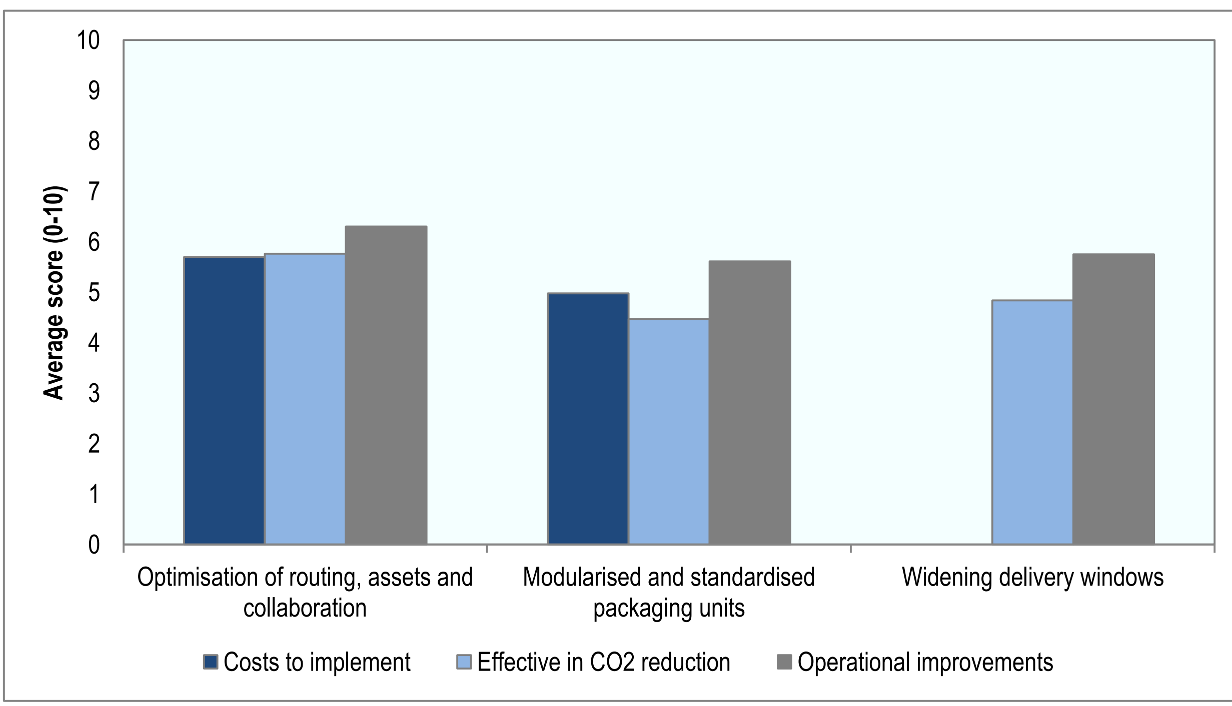
Figure 8. Insights for policy, tested measures and uncertainties discussed in opening session

Insights for policy	Tested measures	Uncertainties and open debates
• Needs to move higher on the decarbonising policy agenda. • Mostly private and profit driven sector. Private companies will play a leading role. • Different regions might require different pathways and decarbonising strategies. • No mature alternative fuels for deep decarbonising of long haul. Further research required on different potential options. Current state of knowledge favours hydrogen, electric roads and electric batteries.	• Eco-driving, driver training for fuel efficiency. • Alternative fuels for urban operations, namely electric batteries. • Relaxing weight and length regulations for heavy trucks on specific corridors. • Improve data collection and indicators to measure vehicles capacity utilisation. • Expand coverage of fuel economy standards and increase adoption of vehicle efficiency technologies. • Renew fleets and improve diesel quality (reduce “black carbon”) on developing countries.	• Demand management policies, decrease transport activity (tkm). Particularly sensitive for developing countries. • Decelerate logistics and relaxing "Just-in-time". Easy savings could be achieved by limiting vehicle speeds, but problematic to relax delivery times. • Modal shift. Probably higher potential in regions with concentrated demand on long corridors (e.g. China, India, South Africa).

Logistics and supply chains

This section focuses on how changes to logistics and supply chains might contribute to decarbonising the sector and what the resulting policy implications are. Improved vehicle loading or the tonnes moved by km driven (tonne-km / vehicle – km ratio) is a key driver of emissions decrease in the logistical field. This implies reducing the number of empty trips or km driven, increasing the use of available capacity in the vehicle (which involves optimising three measures of capacity: volume, weight and space floor) and reducing the overall km driven by vehicle while delivering the same amount of goods. Examples of initiatives that have the potential to improve vehicle loading are: Logistical collaboration, relaxing "Just in Time" pressures, digital freight matching and consolidation of urban deliveries.

Figure 9. Rating of logistics-related measures



Source: ITF expert opinion survey (2018).

A fundamental fact encompassing this discussion is that freight is a commercial business operated by private companies. In order to change behaviours in the industry and adopt new logistical practices it is necessary to leverage the business case for new proposals along with their wider societal benefits. This is a critical difference from the passenger transport side where public bodies and authorities are much more involved (including in the direct provision of services) and trip choices are associated with personal behaviour. For instance, it is estimated that large savings in emissions can be obtained by having cross company collaboration in logistics. That will only happen if the companies themselves adopt these new practices. But policy does play a key role by enabling and helping these processes move along. An important distinction to make is between the actual measures that decrease emissions which will be implemented by businesses – e.g. optimising routes and use of assets – and policies that can allow and encourage their adoption – e.g. revising regulations that restrict night time deliveries.

The expert opinion survey touched on several measures that can potentially lead to fewer emissions. Examples of such initiatives are the optimisation of routing assets and collaboration between different companies. The introduction of modularised and standardised packaging units could also have an important impact, ultimately leading to the "physical internet" that takes asset-sharing and collaboration to its maximum. Another example is the widening of delivery windows. The reader's guide provides brief definitions of these measures. All these initiatives are related with the organisation of deliveries and operations. The impacts are on the increase of the tkm/vkm ratio or average loads, increasing capacity utilisation and fostering a more efficient use of resources.

In the expert opinion survey the respondents were asked to rate different initiatives on several criteria, 10 being the highest and most positive score and 0 being the lowest. Optimisation of routing, assets and collaboration were considered the most effective logistic measures to reduce emissions (see Figure 9). All of these measures scored higher in operational improvements than in emissions reduction. This indicates that there are inherent benefits in pursuing these measures from a business perspective. Nonetheless, there are also barriers to their widespread implementation.

Figure 10. Barriers to widespread adoption of logistic related measures

	Optimisation and collaboration	Modular packaging units	Widening delivery windows
1	Industry-level coordination and co-operation	Industry-level co-ordination and co-operation	Goes against market trends
2	Market structure and lack of scale at individual company level	Market structure and competitive pressure	Permits, standards and regulations
3	Cultural barriers in the industry	Vehicle design	Cultural barriers in the industry/Lack of government support and incentives

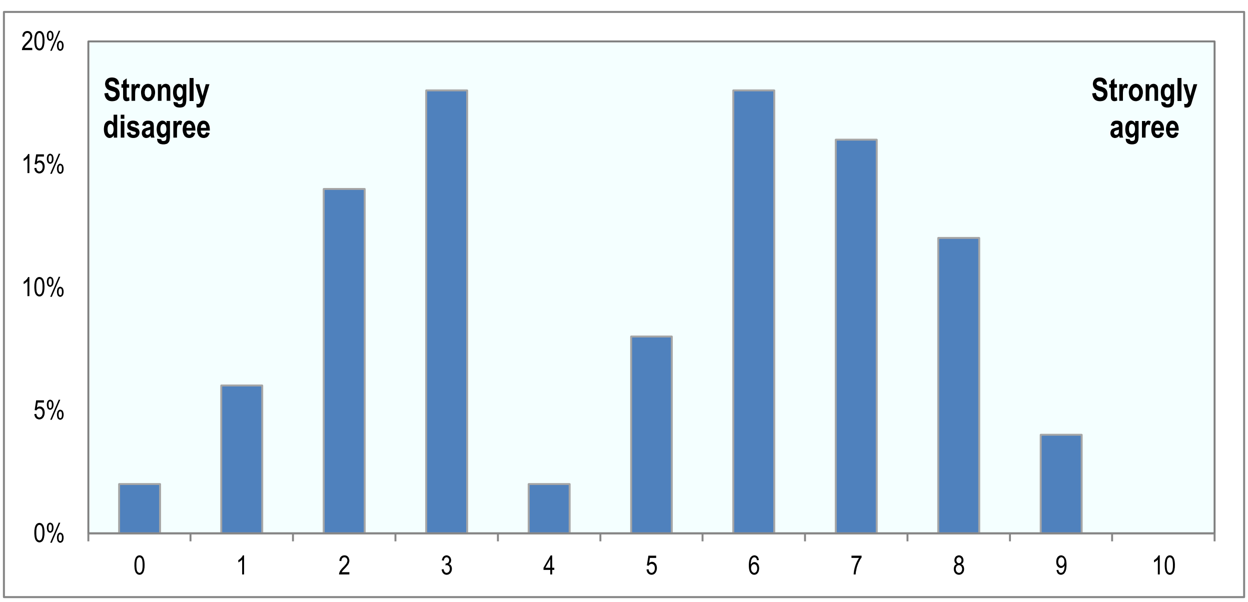
Source: ITF expert opinion survey (2018)

Industry-level coordination and cooperation was selected as the main barrier to a widespread adoption of optimisation and collaboration and modular packaging units. The second barrier identified was the market structure - including lack of scale at individual company level and competitive pressure. For widening delivery windows the number one obstacle is that it goes against the current market trends of ever increasing service levels and shorter delivery times. Existing permits and regulations are the second greatest barrier. Another barrier to moving to new types of a modular packaging system is the heavy investment in existing handling systems and the adaptation of warehouse racking and materials handling equipment to these legacy designs.

It is a fact that the road freight sector is very fragmented with a great proportion of small scale companies finding opportunities to optimise internal assets utilisation limited. Greater coordination and cooperation across the industry would surely help. There is also a culture of competiveness that helps lowering transportation costs, but can make it harder to cooperate. Still, there are digital tools that allow cooperation even across a great number of atomised agents that can enhance collaboration. The current regulatory framework ranked low in the obstacles to more collaboration - it ranked in sixth place among eight alternatives. But antitrust laws can indeed hinder efforts for horizontal collaboration in logistics and have already prevented some experiments. An important challenge to the industry, but also for policy-makers, is to deploy new digital technologies to enhance cross company collaboration and increase logistics efficiency while complying with antitrust laws. This is a key issue further discussed below.

Relaxing delivery times in general goes against market trends, but there is a strong case for moving some urban deliveries to off-peak traffic periods (Sánchez-Díaz, Georén, and Brolinson, 2017). This has the potential to reduce congestion, save time, decrease staff stress and increase safety and reliability. It would result in more efficient operations and less fuel consumption hence reduced emissions. These can be quite significant ranging from 45% to 67% less emissions (Holguín-Veras et al., 2016).One of the key obstacles is local regulations that restrict off-hour deliveries (OHD) in residential areas, which is often associated with noise concerns. These can be overcome with incentives to adopt low noise technologies and vehicles. Having enough participation from the industry, namely receivers, is also critical to have enough scale to sustain carriers' OHD operations. Cost savings are important enough to motivate carriers; generally receivers are the ones requiring incentives to adopt OHD. The implementation of OHD provides a clear example of the challenges of public policy dealing with logistic operations: the need to remove regulatory barriers, but also provide incentives for operational-behavioural changes of different stakeholders from a predominantly private sector activity.

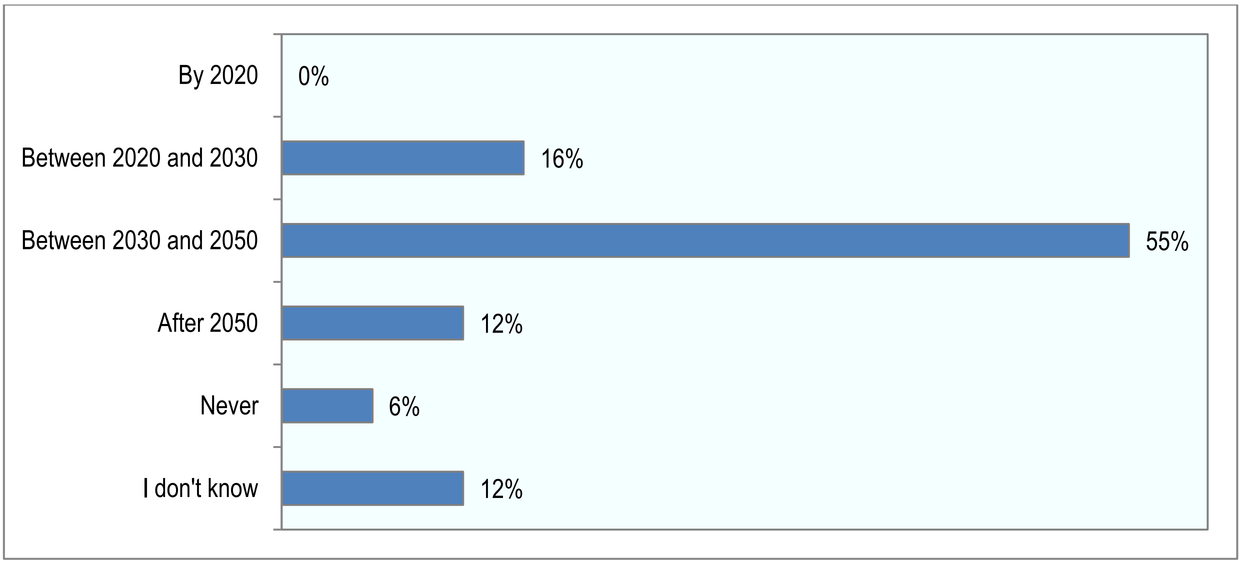
Figure 11. Is it impossible to increase vehicle capacity utilisation if delivery windows are not relaxed?



Source: ITF expert opinion survey (2018)

Increasing levels of service and ever tighter delivery windows are possible reasons why average loads and empty running have not significantly changed in the EU, with some studies even mentioning a decrease in capacity utilisation (Transport & Mobility Leuven, 2017). When asked if it is possible to increase capacity utilisation without widening deliveries the answers were sharply divided. A group of respondents clearly agreed with the statement that it is impossible to increase capacity without widening the delivery windows (even when other measures such as optimisation and collaboration are used), while another group refuted this statement. This is a question closely related with the "decelerating logistics" debate which is far from concluded.

Figure 12. When will "The Physical Internet" be in widespread use?



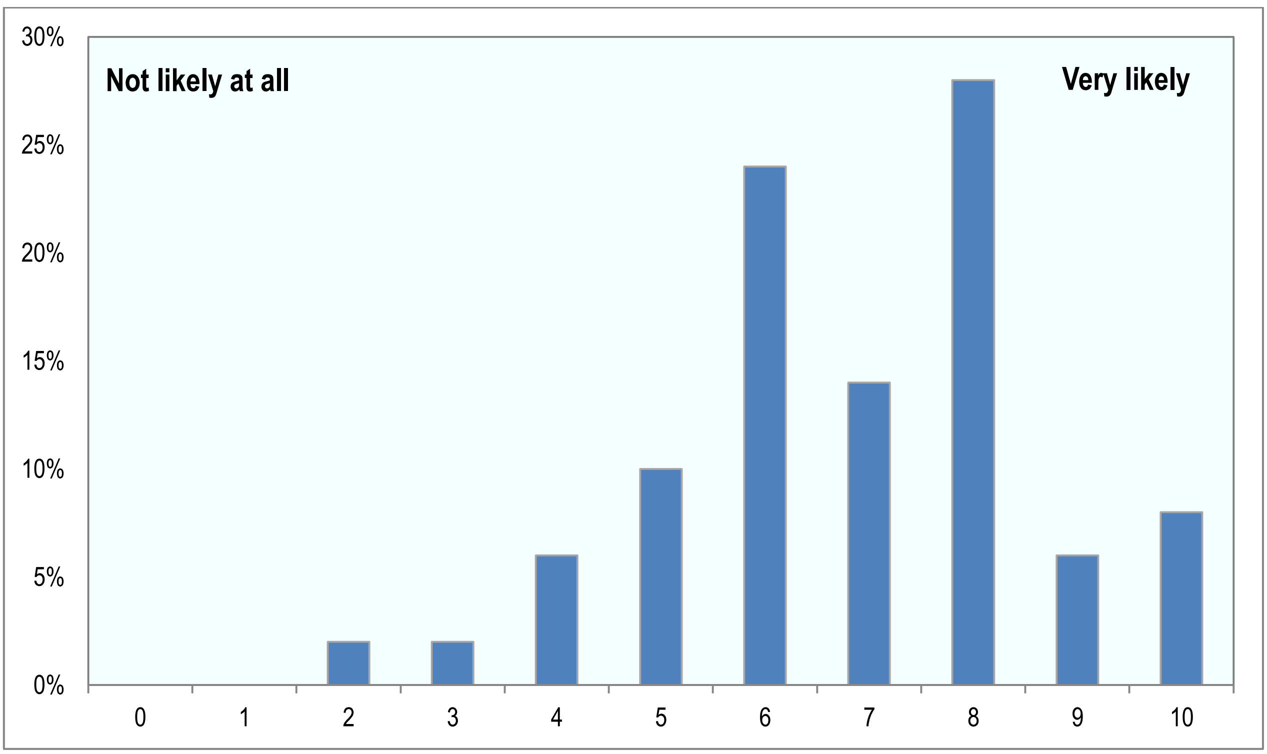
Source: ITF expert opinion survey (2018)

Asset-sharing and collaboration taken to its maximum extent coupled with new modular standardised packaging units can lead to the "Physical Internet". Most respondents think this open shared-global logistics system will be a reality, though not in the short-term. As for its effectiveness it was considered similar to optimising routes, assets and collaboration. Up to 20% energy savings could be delivered by such a system according to some estimates. The scepticism surrounding the actual deployment of the "Physical Internet" mirrors much of the same issues already discussed for collaboration across different companies. In addition, the employment of standardised modular units could create new monopolies and choke points on the logistical chain. The relocation of empty units could also add to transport costs and emissions.

Being an imminently commercial activity companies involved in logistics and road freight have an incentive to minimise their costs and efficiency. But their first aim is to maximise profits hence the importance of driving up revenues. It might make perfect sense to take on extra costs if this can be compensated by increased revenue. Furthermore, even in logistics, transportation is not the only cost companies have to contend with (e.g. inventory or warehousing). It can be argued that current transport costs are too low to further encourage efficiency gains (hence the stable empty returns and capacity utilisation). Another overall caveat to increased efficiency is the lack of available accurate information to identify opportunities to increase efficiency – and even to accurately estimate possible gains. This is especially true for public authorities. There are consolidated practices of collecting and analysing data from passenger transport, but there is less available data and research into freight movements and their impacts – particularly at the urban level.

It is also important to recognise that the logistics sector - and transport at large - is undergoing substantive changes. E-commerce has been steadily growing and it is predicted to further increase. This has already affected the logistics sector and more changes are likely to happen. In the expert opinion survey e-commerce was the most likely trend to be present by 2030 (see Figure 35). Respondents also think major e-commerce retailers will play an increasingly dominant role as logistics services providers. Actually, in the survey, new entrants were identified as the number one private agents to lead changes in the sector (see Figure 36). At the same time boundaries and roles are shifting, with retailers becoming logistic suppliers and logistic suppliers entering retail. Personal trips for shopping purposes are partially replaced by deliveries and personal vehicles are being used for deliveries (e.g. crowdshipping). These emerging trends will be further discussed in another session, but again there is lack of accurate data to evaluate which impacts these new phenomena are actually having on traffic and emissions.

Figure 13. How likely is it that large e-commerce companies will increasingly play a dominant role as logistic services providers?



Source: ITF expert opinion survey (2018).

Presentation summaries

Platform for collaborative transport

The presentation addressed why collaboration between different companies, namely shippers, is important to increase the efficiency of transportation and why it is not happening more. A "real world" experiment in horizontal collaboration between shippers was presented, followed by the ongoing development of CARGOSTREAM a Pan-European open platform which aims at scaling up collaboration. CARGOSTREAM is part of the wider EU funded Clusters 2.0 project. Other initiatives required to foster collaboration were also shown, such as the "Transformers" project- that includes innovative loading efficiency measures for trailers - and "Modulushca" – a new modular standardised packaging unit.

From a shipping perspective collaboration in transport is important both from a social responsibility and an economic efficiency perspectives. Companies are willing to take social responsibility – promoting efforts to reduce emissions and congestion- if supported by economically efficient measures. The latter are related with a service element - namely the decrease in truck driver availability – and an interest in decreasing costs. According to the EU funded CO^3 project (CO3, 2018) 20% to 25% of trucks run empty, of the less than 80% remaining only about 60% of available capacity is used (considering weight and volume restrictions) which means that only around 48% of current capacity is being used. For a shipper there is a great interest in saving costs, increasing asset use and reducing fuel consumption and emissions. But there are limits to what individual companies can do to increase efficiency in transport. Collaboration can unlock a great potential in the optimising of resources.

There have been limited experiments of horizontal collaboration between shippers. In one case, heavy weight and light products were loaded together which lead to greater capacity utilisation. This involved companies synchronising loads and the employment of synchromodality for the use of intermodal transport. The results were promising with sizeable savings in costs and CO_2 emissions. Furthermore, the experiment shows it is indeed possible to apply these logistic concepts to the “real world” with benefits both for the companies involved and society as a whole. But this and other “real world” tests remain isolated cases. So the question is: What can be done to scale up these experiments?

Strategic collaboration through data sharing platforms can be a critical part of the solution. In the case of CARGOSTREAM shippers, logistic service providers (LSPs) and other operators collaborate through a neutral platform. This platform was developed by a third party, a startup that owns the platform and provides value-added services in data analytics – mostly combining data from different sources and employing it for optimisation. One important feature of this set up is that it allows the optimisation of transport across a pool of multiple companies and not simply one-to-one. Data is owned by the source, anonymised (although it can be shared and made public if a company so wishes) and aggregated for finding optimised solutions.

After, different requests are matched through the optimising process – which also takes into account historical data and some preferences (e.g. which cargo types can be mixed) – there are two ways in which a collaborative solution can be set up. One is for the shippers to directly work together. This is not the most appealing option since it opens the door to non-compliance with antitrust regulation. A more interesting alternative is for the platform to directly implement a collaborative solution, including purchasing the services of LSPs. This way the platform is able to keep a chinese wall between companies but at the same time have their data, combine it and implement a solution.

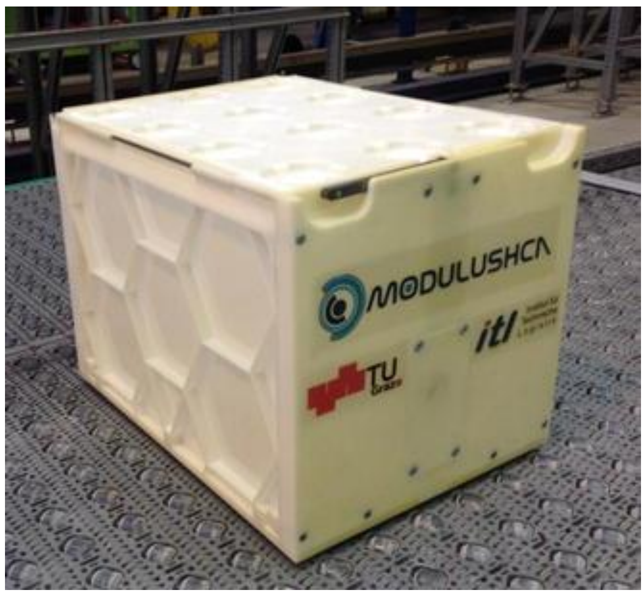
A solution derived directly through the platform and valued-added service was already implemented leading to a significant decrease in truck empty running, cost savings and fewer emissions. Currently the platform is focused on truck transport and finding round trips – or reducing empty runs also known as backhauling. But the plan is for it to also optimise vehicle loading (also known as co-loading) and include intermodal solutions. It should also be noted that this approach is easier to implement for high volume orders with low volatility.

The platform is also interesting from a LSPs perspective. If haulers/LSPs have imbalanced flows shippers can make offers to balance them (reducing empty returns). This highlights an important element regarding logistical measures; the need to offer incentives to all agents directly involved in operations.

Besides this type of neutral platform there are other measures that can ease collaboration and increase efficiency. The “Transformers” project aimed at developing more energy efficient trucks and trailers. Innovations to the trailers included a multi-section, double floor system that can be independently adjusted with a fork lift and allows stacking pallets. This means it is easier to adjust different volumes and increase load capacity within current weights and dimensioning regulations. Collaboration is fostered by enhancing the ability of combining different loads in the same trailer.

The objective of the "Modulushca" project is to increase collaboration by presenting a design for a system of modular boxes that meet the requirements of the "Physical Internet". . Regardless of the long-term vision this packaging units system facilitates stacking goods in pallets and makes better use of the volume-weight capacity of a trailer, hence requiring less trucks to move the same amount of goods. Fundamental to the widespread adoption of this type of solution is to develop a standard that fits the operations and other requirements of suppliers and retailers.

Figure 14. Physical prototype of the small M-box of the "Modulushca" project



Source: Landschützer, Ehrentraut, and Jodin, (2015).

An empirical agent-based model for urban road freight transport

A project being developed by the Delft University of Technology combines emerging sources of "big data" with agent-based models that are able to simulate behaviour at a disaggregate level. This has the potential to provide accurate estimates for indicators such as capacity utilisation, furthers the understanding of logistic choices and improves estimates of the impacts of policies or new technologies on urban freight transport patterns.

The lack of accurate, disaggregate data along with the analytical instruments to process it has been identified has one of the problems associated with the effectiveness of emission reducing measures for logistics. There simply is a lack of understanding of what the potential of logistic solutions are to minimise CO_2 emissions. For instance, it is difficult to have quantitative analyses of the impacts of road charges without logistic choice models with some level of disaggregation. A policy such as this will produce different impacts for different transport markets, depending on the commodity types and distances. A distance-based charge will have more impact on inter-regional freight transport (or longer distances) than truck distribution patterns in an urban environment. Aggregate commodity flow type approaches fall short, particularly at a city level analysis.

Data access to private company operations from public entities is a critical issue. In this study researchers had access to detailed truck level data collected automatically from private company transport management systems (TMS). This data is actually collected by the central Statistics Netherlands (CBS) who granted access to the researchers. This is sensitive and private information subjected to privacy regulations. Model development had to take these concerns into account with a strict separation between the data analysis component - that had remote access to the CBS database - and the simulation component that generates synthetic shipments and tours. The data that was accessed contained information on more than two million individual trips, with details including the truck license plate and its characteristics, origin and destination, exact start and stop times, load and unloading location of shipments together with their attributes (e.g. gross weight, shape, volume, type of goods). It should be highlighted that this level of data disaggregation allows for a fairly accurate estimation of capacity utilisation. Difficulties in assessing this indicator was one of the reasons mentioned in the previous section for under-estimation of the potential logistical contribution to road freight decarbonisation.

At its current stage of development the model is able to generate synthetic truck patterns in a city, i.e. it simulates all truck tours within the city with information such as the vehicles used for each tour, commodities distributed, and load and unload locations with their timings. Among other things this can be used to quantify emissions by vehicle type or assess the potential impacts of establishing collection points. A route assignment module – not yet deployed - can also allow identifying bottlenecks in the infrastructure network. At more advanced stages agent-based modelling can be used to analyse behavioural responses to new technologies and logistic trends. For instance it is possible to better simulate the impacts of different strategies for road user charges (e.g. by vehicle type), environmental zoning and new technologies (possibilities for horizontal collaboration or growth in e-commerce).

Box 2. Agent-based models for logistic choice behaviour

Urban planners face challenges to make urban freight transport more sustainable: reducing urban congestion, providing reliable delivery windows, decreasing logistic costs, reducing emissions and improve safety. Policy makers are faced with a broad set of solutions to mobilise the reduction of carbon emissions, but lack policy support tools that would help analyse the effectiveness of possible solutions.

Emergent data and agent-based freight transport demand models provide the possibility to simulate expected impacts of a variety of solutions, in a structured consistent manner. In the MASS-GT project we aim to develop a comprehensive simulation framework that describes logistic decision making in the context of urban transport planning. Empirical basis is provided by a large dataset with observed freight transport data for The Netherlands. Part of the data has been collected using an automated procedure to report complete freight trip patterns from the transport management system. This provides denser and complete data compared to conventional internet surveys.

To manage simulation complexity a stepwise approach is followed. First, a baseline model was developed that applies a data driven simulation approach. Currently the first behavioural logistic choice models are being developed that will be implemented in the second version of the agent-based modelling framework. These choice models include a model for simultaneous shipment size and vehicle type choice, and a tour formation model. Future work will consist of further extending the framework with the stepwise integration of more advanced discrete choice models for logistic decisions.

Michiel de Bok, TU Delft

Voluntary programmes

Voluntary emission reducing schemes involving businesses in association with public or civil society are part of the journey towards decarbonising. Lean and Green logistics is a European example of such a scheme. This initiative emerged from the Connekt network of over 400 public and private organisations. One of the initiators of the scheme was the Dutch Ministry of Infrastructure and the Environment. It highlights how the industry can lead the efforts to decarbonise, but also the role of public policy nudging business towards that goal.

The key lever of the program is to award organisations that commit to an action plan for a 20% reduction of their CO_2 emissions within a five-year program. A star is given when they reach the targets set out in their action plan. Further stars are presented to organisations that build on that and set up new sustainability targets. Emphasis is placed on continuous improvements with the ultimate goal of a five star reward when emissions are reduced to zero. Organisations that take part in this program work together and lead the way in sustainability and maintain leadership in this field.

This example shows how to incentivise efforts that combine cutting costs, improvements to operational performance and emission reduction. Besides the direct cost savings incentive, companies that take part are recognised publicly and among their peers for this drive towards decarbonisation. They also take part in a community of organisations that share their commitment. Being leaders in sustainability increases their know-how and can give them a competitive advantage when compared to companies that lag behind in this objective.

There are several ways in which the program assists organisations in reaching their targets, such as fostering the development of guidelines and tools to calculate emissions, the exchange of best practices and anonymous benchmarking between members.

Another initiative in which Connekt is involved is Lean analytiX. This is an application developed by a start-up that receives data from companies, analyses it and provides insights into their current operational performance and emissions. These insights can be used by retailers, shippers and other companies to reduce waste in their supply chain. One of the features of this software is that it can combine different data of varying quality. Companies do not need to invest or upgrade their IT system to obtain results. The data used is owned by the companies and shared in a trusted way. Around 80 companies were involved in the testing and validation of this approach. There was some initial scepticism into what additional understanding of their own operations this tool could provide, but initial results indicate that this can indeed contribute to improve their operational performance.

Discussion

The current importance of data for logistics and decarbonising cannot be over-estimated. A first area where data plays a critical role is policy making. The data required to properly estimate critical indicators like capacity utilisation or impacts of different zoning schemes for urban areas currently exists, but it is mostly property of private companies. Access to private data from public entities is a critical issue. This data is required for better informed policies. Part of the data has sensitive commercial information and there are privacy concerns. These should be properly taken into account when accessing, analysing and sharing information obtained from the analysis. Besides the data itself, new modelling tools and more disaggregated approaches would help to obtain more meaningful insights for policy makers – and the industry.

Collaboration between companies has the potential to leverage great savings in costs and emissions. Until now inter-company collaboration has been only implemented at localised experimental levels. Scaling-up these experiments is critical to unlock the potential of logistic measures in decarbonising. Data sharing and third parties (or trustees) play a crucial role in this endeavour. A third party can collect data from different sources, combine it for analysis and act on it -e.g. ordering transport services from a logistics supplier that combines loads from different shippers. At the same time it can keep information from these different sources private, preserve anonymity and maintain a “Chinese wall” between them. The latter is important to comply with antitrust regulation and avoid legal risk – an important barrier to foster collaboration. Digital technology offers solutions that allow for collaboration and comply with antitrust concerns. From a policy making perspective it is very important that antitrust regulation is not an obstacle to logistical collaboration.

New modular packaging units can enhance collaboration and are a better use of capacity. Developing a standard that meets the requirements of different agents in the industry (retailers, shippers, LSPs) is necessary for widespread adoption. This is relevant for other areas too, such as emissions accounting.

Road freight and logistics is a commercial business. Industry agents are the ones that ultimately define their operational procedures and supply chains so they need to play a leading role in decarbonising the sector. Companies have a direct self-interest in improving their operational performance and to cut costs. Measures and policies designed to reduce emissions can and should be combined with improved efficiency and costs savings. This is a fundamental incentive for the sector to reduce emissions. It is also important to recognise that there are different private side agents –e.g. shippers, retailers, LSPs – with different requirements. Measures that can reduce costs for some company types might not be so attractive to other players (e.g. suppliers and receivers in off-peak deliveries). Policies and initiatives that align the interests of all agents involved will be easier to implement.

Recognition among peers and the wider public is another incentive for businesses that want to lead efforts to decarbonise. Voluntary schemes where companies and other partners cooperate to achieve targets and implement pathways toward greater sustainability also play a role. Governments and other public entities can also be involved in kick-starting these initiatives.

Logistics and supply chain options potential to reduce emissions can be as high as 30%-50%, but there are few case studies with substantiated costs and benefits. There are anecdotal examples of collaborative schemes, but so far there is no widespread adoption. Existing available data does not show a significant contribution of logistic solutions to emission reductions. Moreover, there is a lack of data to properly assess the current situation and estimate the impacts that logistic solutions might have.

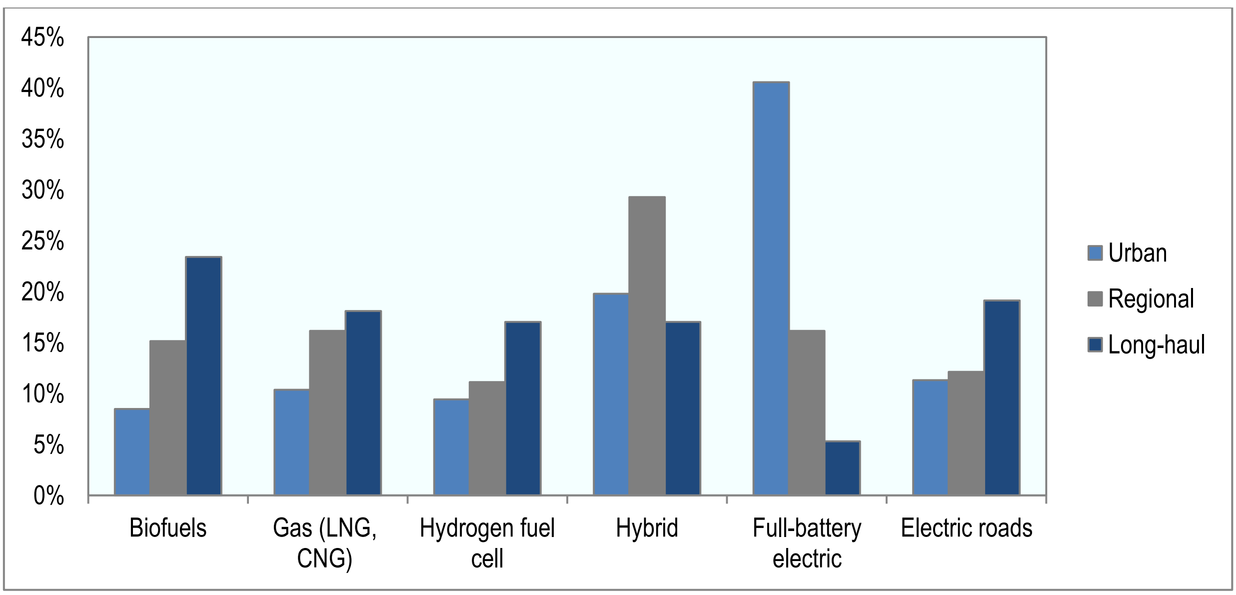
Key insights obtained in this section:

- Public entities need access to privately owned and generated data, while acknowledging the sensitive commercial nature of such data and privacy concerns.
- Antitrust regulation should not be a barrier to logistical collaboration. Digital platforms operated by neutrally-trusted third parties offer a promising pathway to overcome these barriers and unlock the potential of collaboration.
- Combine wider societal goals like emissions reduction with private business aims such as cost savings and an increase in operational performance.
- Not all private agents involved have the same requirements. Measures to decarbonise should be attractive for all agents involved, shippers, retailers, hauliers and other stakeholders.
- Development and adoption of standards for new equipment types (e.g. modular packaging units) or emission accounting is important for their widespread use.
- Recognise companies that lead efforts to decarbonise. Voluntary schemes that promote sustainable solutions are also part of the solution.

Alternative fuels

Alternative propulsion systems to the traditional diesel (or petrol) internal combustion engine are the focus of this section of the report. These include: biofuels, gas, hydrogen, electric batteries and electric road systems (ERS). They involve investment not only in vehicles, but the refuelling and recharging networks. The costs and emissions of producing the fuels also need to be taken into account.

Figure 15. What are the most cost-effective alternative fuels for each operation type?

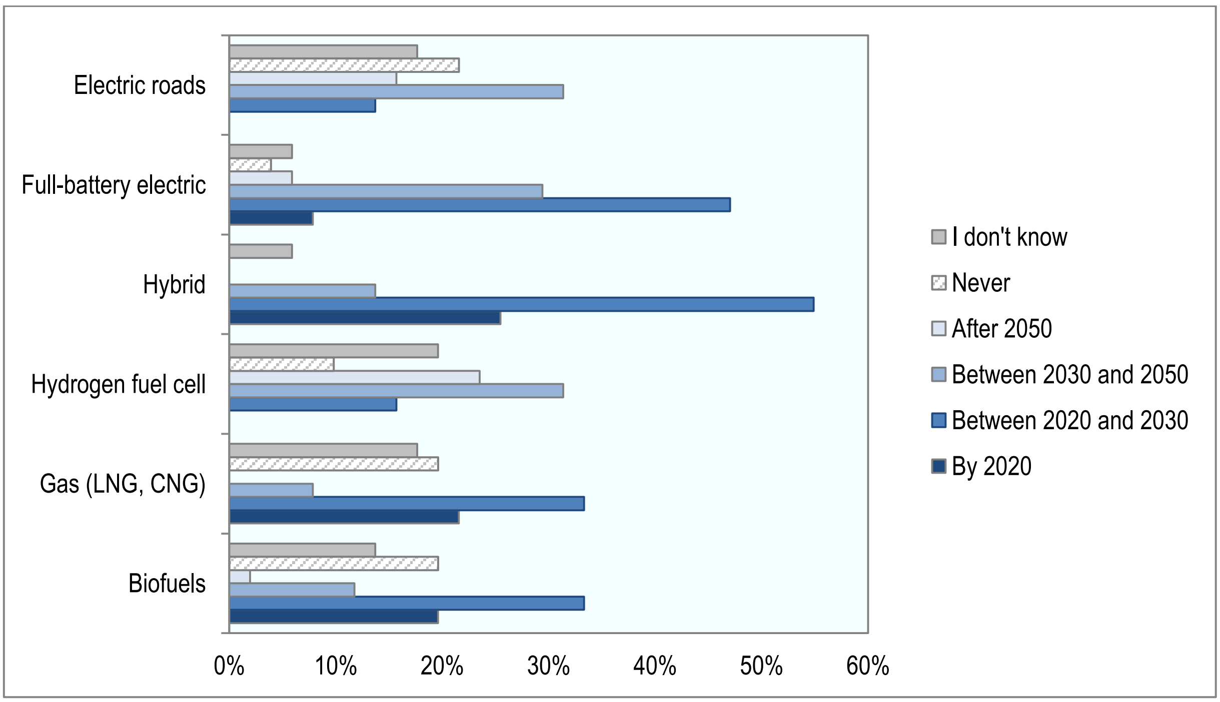


Source: ITF expert opinion survey (2018)

A first important insight is that there is no single solution that fits the requirements for all operation types. Battery electric vehicles were clearly the favoured option for urban type operations. There is a wide consensus that current technology and expected developments will make this option ever more attractive for the vehicle sizes, ranges and operational patterns involved in urban distribution. But this same solution ranked last when it comes to long-haul operations. Recently manufacturers and other companies have been investing in electric battery heavier vehicles - e.g. Tesla (Tesla, 2017), BDY (BYD, 2018), Daimler (Hirsh, 2018). There have been pilot projects with medium freight trucks for deliveries (Morris, 2013). But for now even the heavier trucks pilot projects are mostly directed at the delivery market, not the long-haul. In the short- to medium-term it is an option directed especially at light commercial vehicles for deliveries and urban or regional transport (Heid, Hensley, Knupfer, and Tschiesner, 2017).

It is increasingly hard to find cost-effective alternatives as vehicle sizes and range increase. Moreover, in urban operations the fleets of vehicles generally return to the same depot or network of depots after running their daily routes in the city. This makes it easier to set up the refueling or recharging infrastructure for any of the alternative fuels. For longer trips the availability of recharging stations along the journey becomes a more pressing issue. In fact, biofuels are the preferred option for long-haul trucks in the survey. An important advantage some of them have is the ability to use the same existing oil fuels refueling and distribution network (drop-in fuels). But this option is not without its caveats, e.g. difficulty to scale up production or their full life cycle well-to-wheel emissions (see Figure 18). In fact for the long-haul there was no clear cut solution. Ranking close in preference to Biofuels were, respectively: Electric roads, Hydrogen and Gas.

Figure 16. When will these alternative fuels be in widespread use?

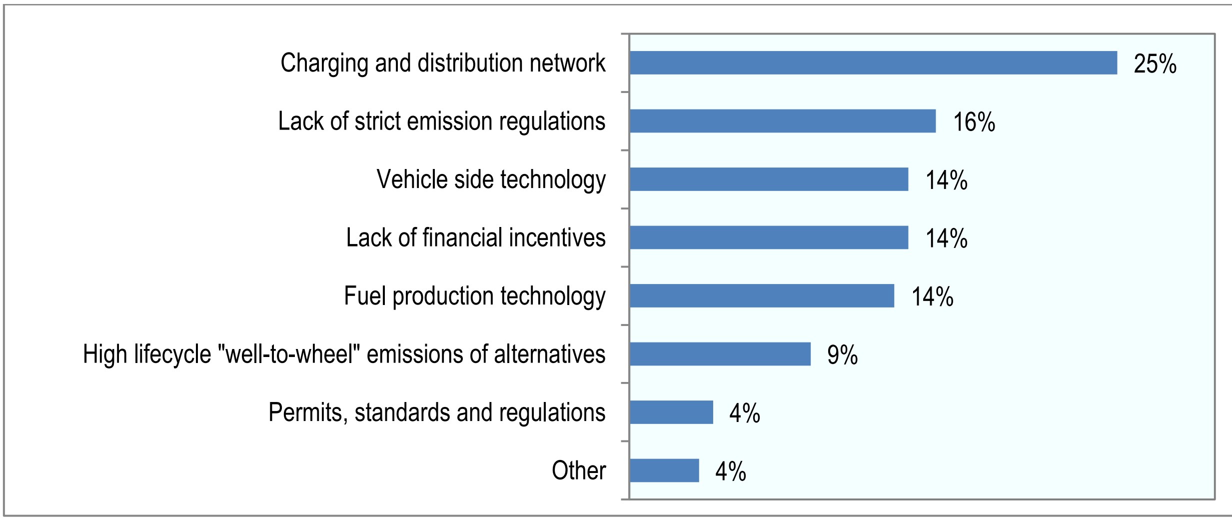


Source: ITF expert opinion survey (2018)

Hybrid vehicles have the fastest adoption according to the survey results. More than 50% of the respondents also think electric battery vehicles will be in widespread use by 2030. The same happens for Gas and Biofuels, but opinions are more divided regarding these fuels. Compared to electric batteries, there are more respondents that think Gas and Biofuels will already be in widespread use by 2020. But at the same time there is also more scepticism with a high number of participants thinking that these fuels will never be in widespread use or do not know – in total more than 30%. Electric roads and Hydrogen fuel cells are seen more as long-term solutions with a high level of uncertainty. Answers saying these will never be in common use or do not know are above 30%.

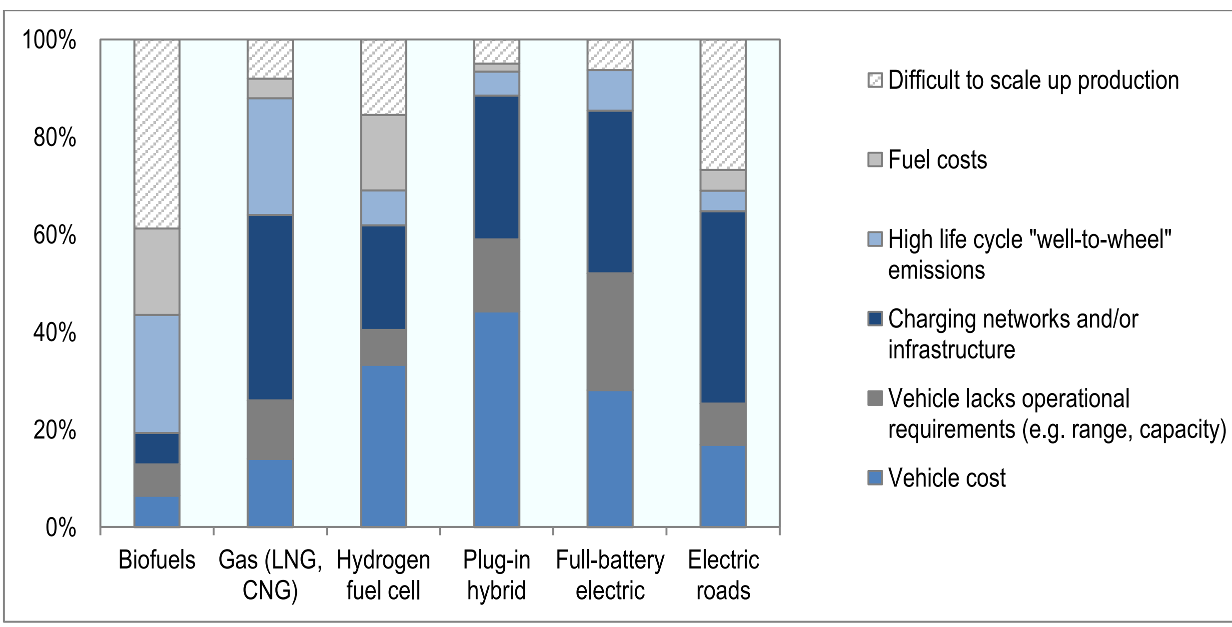
The major barrier to scale up the adoption of alternative fuels is the deployment of charging or refueling stations and the distribution network for these fuels and this is dependent on the type of fuel. For Biofuels the difficulty to scale up the production is the major barrier. High "well-to-wheel" emissions are also a factor when considering Biofuels and Gas, two of the favored options for the long-haul.

Figure 17. Overall barriers to scale up the adoption of alternative fuels



Source: ITF expert opinion survey (2018)

Figure 18. Overall major barriers to scaling up the adoption of alternative fuels



Source: ITF expert opinion survey (2018)

Presentation summaries

Biofuels, gas and hydrogen alternatives for heavy-duty trucks

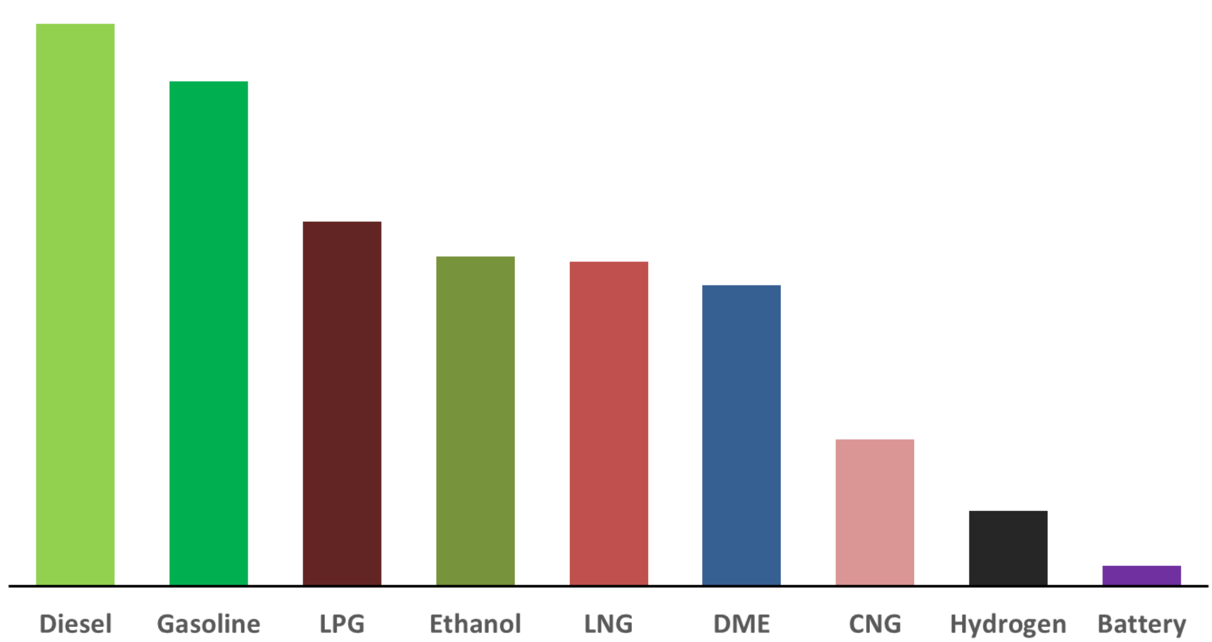
The discussion on alternative fuels started with a glance through some of the options including different types of biofuels (FAME, renewable diesel and Ethanol), gas (compressed and liquid natural gas) and hydrogen.

According to Exxon's energy outlook demand for energy for heavy-duty trucks will grow up to the 2040 horizon mainly driven by GDP growth across all regions of the world. Diesel will still be the main fuel in place, with some growth of gas and biofuels. During this period the growth in fuel demand will be attenuated by fuel efficiency technologies and to a lesser extent by an increase in truck sizes – which can simply mean a shift from medium to heavy trucks in the developing world. Operating inefficiencies in logistics and congestion will add to fuel demand.

A first critical aspect to consider is the energy density of different fuels. By volume, diesel has clearly the highest density compared to other alternatives far above hydrogen or electric batteries. This gap would be reduced in a tonne-km basis, since electric engines are more efficient than diesel but there would still be a significant gap.

Different types of liquid fuels produced from organic sources are already commercially available. They can include FAME (Fatty acid methyl ester), Ethanol and renewable diesel. Some of these fuels have the advantage of being bendable with diesel. Ethanol is in widespread use in the United States and Brazil. This means that they can use the current refuelling and distribution infrastructure. Renewable diesel is chemically very close to fossil diesel and can be used on existing truck engines without any limit to blending. There are ongoing experiments with heavy-duty engines that can use a 95% mix of Ethanol.

Figure 19. Volumetric energy relative to diesel



Source: Mizan (Exxon Mobil presentation) (2018).

Nowadays most biofuels are crop based – e.g. sugar cane, corn or vegetable oil – which raises indirect land use change (LUC) concerns. Even though they are already in use, globally they still represent a small portion of total fuel consumption, although they can make up a significant portion of the fuel use in some countries (e.g. Brazil and the United States). A dramatic increase in the use of crop based biofuels would mean a substitution of food crops and large scale conversion of pasture, savannah, or forest land unless mitigated by yield intensive crop technologies and practices as well as appropriate land use policies - see for instance, (Macedo et al., 2012) or (Nepstad et al., 2014). The carbon emissions originating in these land use changes can offset any emission saving potential from biofuels (Valin et al., 2015). If these fuels can be produced from waste, algae or cellulosic sources they can become a much more attractive option for decarbonising. However, up until now these non-crop solutions have proven difficult to scale up. Both crop and non-crop biofuels that involve a fermentation process can offer even lower lifecycle GHG reductions if coupled with CCS.

These caveats do not disqualify biofuels from the set of available solutions. For instance, the impacts of indirect land use change can vary greatly from country to country. Brazil is a case study that demonstrates how the widespread adoption of Ethanol produced from sugar cane can contribute to the decrease of emissions even when total life cycle and land use changes are taken into account - (Rothkopf, 2008; Schroeder, 2010; La Rovere, Pereira, and Simões, 2011). Nonetheless, conditions in Brazil cannot be easily reproduced at a global level - the climate suitability for sugar cane, amount of available arable land and large agro-industrial complex – as shown by other examples, e.g. (Transport & Environment, 2018a) or (Cazzolla Gatti, Liang, Velichevskaya, and Zhou, 2019). This highlights an important insight: the pathways to decarbonising should be adapted to the specific conditions of different geographies. Solutions that might have a strong economic case and emission saving potential in some regions might not be applicable to other places.

Gas powered vehicles can use Compressed Natural Gas (CNG) or Liquid Natural Gas (LNG). The first is more effective for smaller sized vehicles and particularly suited when the vehicles return every day to the same depot (easier to refuel and have the necessary infrastructure). LNG is more suited to heavy-duty vehicles for long-haul operations. Natural gas has a lower combustion temperature than diesel, hence it can lower tailpipe emissions and can potentially meet air quality emissions standards with less after-treatment. Nonetheless, there are issues with methane leaks and boiling point that can offset the carbon emissions savings assumed in baseline scenarios (Alvarez et al., 2018). In fact, methane can be 28 times more damaging than CO_2 (Shindell et al., 2013). Moreover, the tailpipe emission reductions possible with LNG are limited when compared to the more efficient diesel engines (Transport & Environment, 2018b), (Vermeulen, Verbeek, Goethem, and Smokers, 2017). For the most recent Euro VI diesel trucks there are no significant differences between Gas and Diesel standards, if anything they are more stringent for Diesel regarding particle number (PN). The current high cost of LNG vehicles is also a caveat. Most gas in use comes from fossil sources. It is possible to obtain it from bio sources and waste, but the gas produced this way comes with a high level of contaminants that need to be removed which increases its costs and reduces its availability. It is estimated that the availability of renewable gas is limited (Searle, Baldino, and Pavlenko, 2018).

Dimethyl Ether (DME) is a gas under normal atmospheric conditions. It is non-toxic and has low particulate emissions. It can be efficiently produced from natural gas and potentially a variety of bio sources (including waste). It can be stored as a liquid under moderate pressure hence it is easier to handle than CNG. Current diesel engines with some adaptations can use it. Nonetheless, its widespread adoption would require setting up supply infrastructure.

Hydrogen has the advantage of zero tail pipe emissions. But the most common method of producing it is through steam reforming that uses fossil fuels. It can also be produced from electrolysis of water using electricity, which is a very energy inefficient method. Studies show that given Germanys' current electricity mix, powering trucks with Hydrogen generates more than twice the amount of greenhouse gas emissions than diesel trucks (Kühnel, Hacker, and Wolf, 2018). A possibility is to use excess renewable energy to produce hydrogen. But it will probably not be possible to generate enough Hydrogen from excess renewable energy alone (Verkehrswende and Energiewende, 2018). Even if it was, it is not clear if this is the best use for this energy that also needs to be employed for other purposes (e.g. heating systems). In addition, storing and transporting Hydrogen also poses important challenges and the infrastructure for distribution and re-fuelling is not yet in place.

Whatever the type of alternative fuel to adopt, it should be appealing for the fleet owners. The widespread adoption of alternative fuels requires a solid business case. Several of the existing alternatives are conditioned by lack of supply and refuelling infrastructure. In addition, several fuel generation processes require carbon capture and sequestration (CCS) to be really attractive from an emission savings perspective. Overall there is still a great degree of uncertainty regarding the widespread use of alternative fuels at a global scale. Exact pathways and alternatives will vary for different regions.

Furthermore, the transition to alternative fuels and zero emission solutions will not happen overnight, increasing vehicle efficiency should still be an important priority. In developing nations this can happen by simply moving much of the transport done by medium trucks to heavy-duty vehicles.

Electric commercial vehicles for cities

During this discussion Renault's experience in the electric light commercial vehicles (LCVs) in city markets was shared along with insights into what can – and cannot - be drivers for success and increased adoption.

Two-thirds or more of the LCVs – vehicles with less than 3.5 tonnes used mainly for commercial purposes – sold in Europe are not for direct transport and logistical activities. They are used by and for a range of activities including craftsman, agriculture, gardening, public services and a variety of businesses.

Growing concerns about climate change and air quality in cities have contributed to the development of electric LCVs as a solution on an urban scale. Future bans on diesel and gasoline cars in cities across Europe are encouraging the industry to adapt and meet the challenge of providing vehicles powered by alternative fuels. An example is the city of Paris that announced it would ban the use of diesel vehicles by 2024 and gasoline by 2030.

Renault is currently the world leader in electric LCVs, although Chinese manufacturers are rapidly gaining ground in this field and will eventually surpass Renault. In the European market Renault will retain its leadership. Achieving this position required significant investments and was part of a strategic move. This is not something that can happen overnight.

Electric vehicles (EV) are part of an ecosystem where vehicles do not operate per se; they are connected to the electric grid. They require charging facilities and have specific maintenance requirements. There are still incompatibilities between charging and payment systems. It is important to move towards common standards.

Owners of big fleets that operate in an urban environment are the first adopters of electric mobility in a significant scale. Big fleets have specific types of vehicles dedicated to specific purposes and this makes it possible to have an offer that meets these defined requirements. In fact, around 80% of the vehicles sold are modified (many times by third parties) for specialised use and these vehicles will perform the same type of operation for their entire life. The same is not the case for private cars, where owners want a vehicle that can be used for a wide range of purposes. This was one of the main reasons why electric vehicles were first adopted by these big fleets.

Designing these vehicles involves balancing different requirements such as costs, payload and range in order to deliver a product that is attractive to the customer. Not all characteristics are optimised to their maximum potential. Currently, LCVs offered by Renault do not use super chargers. Most professional or commercial clients are not willing to take the extra costs associated with this fast charging option. These costs are associated with dedicated infrastructure and having the personnel to maintain it. Their operational pattern allows using the night time to recharge the vehicles. So, although technically possible – at least for now – it is not financially attractive to have this super charging option.

Technical development and commercial needs go hand-in-hand. Improved batteries with higher energy density and more advanced engines have made a new range of heavier vehicles for urban distribution possible (with payload up to 1 000 kg). One of the main earlier uses of lighter electric vehicles was postal distribution, but as less mail is distributed and there is an increase in parcel delivery the market requires vehicles with more volume and payload.

The market for electric vehicles is increasing, but still only accounts for 1% of total LCVs sales. Without subsidies and other incentives the profitability of investing in these vehicles is limited to a narrow range. Autonomy without recharging limits the distance able to be travelled, but if the vehicles are not used enough then the lower energy costs do not offset the higher initial price. Nonetheless, as the technology and market mature the range of profitability and affordability will increase. Growing volumes of sales and the experience gained will help increase economic efficiency enabling the future expansion of electric mobility.

A technology roadmap for freight decarbonisation

A roadmap that provides the best route towards decarbonising involves implementing now measures with low-adoption barriers that have effectiveness in reducing emissions. Some examples are driver training, optimised routing, heavy capacity vehicles or tyre pressure monitoring, but it also necessary to start reducing the barriers to high impact measures like the electrification of highways.

Technological and logistics solutions are not opposed to one another and the most effective pathway to decarbonise the sector requires efforts at both these levels. It should be noted that most of the energy consumption to move goods happens on heavier trucks for the long-haul. A heavy vehicle that travels fully loaded in both directions will save around 40% of energy per tonne-km. Moving from single trailer vehicles to heavy capacity vehicles can produce savings of 25%. Both types of measures can lead to relevant reductions.

Mainstream adoption of technologies matters. An individually isolated solution that fully decarbonises for a single company will not produce relevant changes. It is necessary to have measures and technologies that can be scaled up and adopted at a national and even global level to have an impact. Given the nature of differences across regions of the world maybe a set of solutions is needed and not just one unique pathway. But these solutions need to be applicable at large enough scales.

Existing technologies in the toolbox for decarbonisation can be classified along two axes. One is their effective potential to reduce emissions, the other is how high the barriers (technical, economic and political) are to their adoption –. For instance, Gas from sustainable bio sources has high potential to reduce emissions, but there are also strong barriers to its widespread application. It is almost impossible to scale up its production for mainstream use. Autonomous vehicles can increase operational performance and allow for some flexibility (e.g. 24h use, including of peak periods). This can save some emissions, but their main benefit will be in cost reduction. Likewise drones employed for deliveries can provide commercial advantages, but they will have negative impacts from an emissions perspective. Higher capacity vehicles are one of the options that do not have high barriers and can deliver significant gains. There are no low-barrier options for zero emission alternative fuels for heavy trucks. Currently the best two options available are hydrogen and electric roads (eHighways). A measure such as the electrification of highways would require significant investment, but some studies show that from the electricity generated Hydrogen would only deliver to the vehicles around 28% of what direct supply of electricity can (Bossel, 2006).

Besides investment to infrastructure, eHighways would spur on changes to the logistics system. For instance, with movement between distribution centres in the edge of cities being done along electrified roads and distribution within the cities by battery electric vehicles. One option to consider for battery vehicles is opportunity charging. A vehicle that charges multiple times for short periods along the day can be equipped with a much smaller battery – and can be a third of the size required otherwise. Nonetheless, this type of charging would require a much denser and standardised charging network.

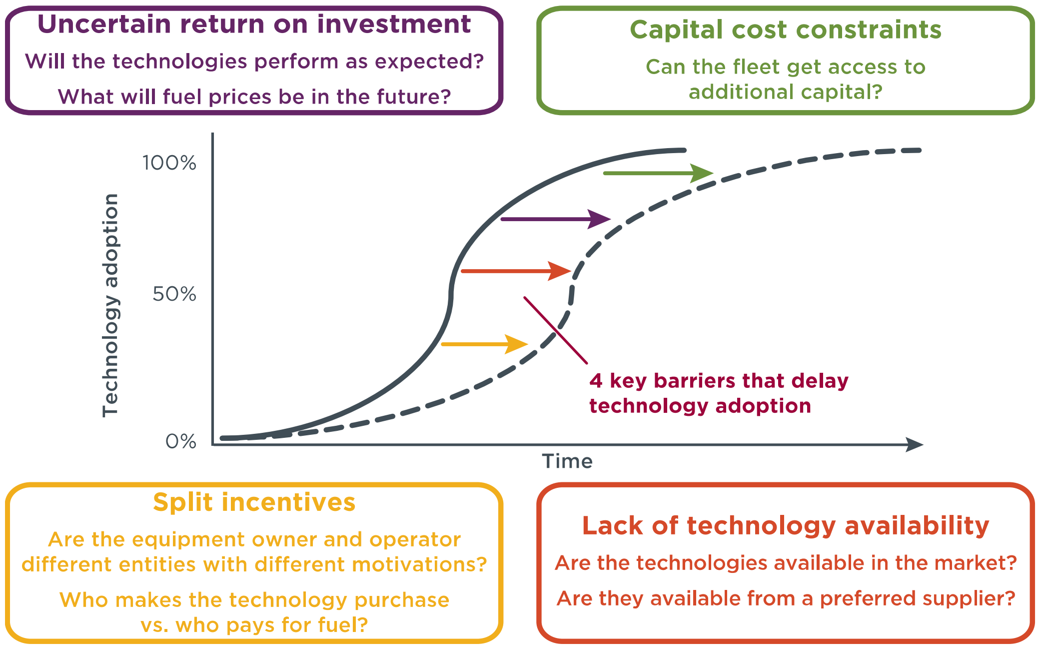
In order to achieve significant reductions in CO_2 emissions – an 80% target for the United Kingdom was mentioned –important infrastructure investments are necessary, mostly from governments. The volume of new infrastructure required is such that the private sector alone will not supply the amount necessary. This is certainly the case for the electrification of highways, but it is also the case for any wide-scale adoption of zero emission fuels given the current state of knowledge.

Discussion

The business case of these alternative fuels and wider technological improvements is of paramount importance. It will be difficult for fleet owners to adopt more sustainable measures if those proposed defy their self-interest. Fuel costs represent more than a third of the total operating costs for road freight in North America (Mizan, 2018) and can be between 20% and 30% in Europe (Panteia, 2018). So, there is indeed an incentive to save in these costs. It is also true that there are fuel efficiency improvements with short payback times or positive net present values (NPVs), but which are still not widely adopted by the industry. The fact is that these improvements – be it already available alternative fuels or retrofits to existing vehicles to reduce fuel consumption – generally involve higher initial costs than the standard vehicle equipment or traditional fuels.

For large companies spending more on efficient transport, even if this delivers a positive NPV, it might bring fewer returns than alternative investments in other areas of its activity. As discussed in the logistics section of this report, the ultimate goal for a private company is not cost reduction per se but increased profitability. Moreover, a sizeable portion of the market is made of small family-sized businesses with low profit margins. In Asia 90% of the trucks are owned by individual drivers, while in the United States 90% of the truck fleets operate with six or fewer trucks. Even when improvements have lower total ownership costs (TOC) these small businesses might not have the available initial capital to invest or may feel they are too risky. These are companies with limited resources where time and efforts are often focused on immediate pressing operational issues, regulatory compliance or business survival.

Figure 20. Barriers to the adoption of fuel-saving technologies in the trucking sector

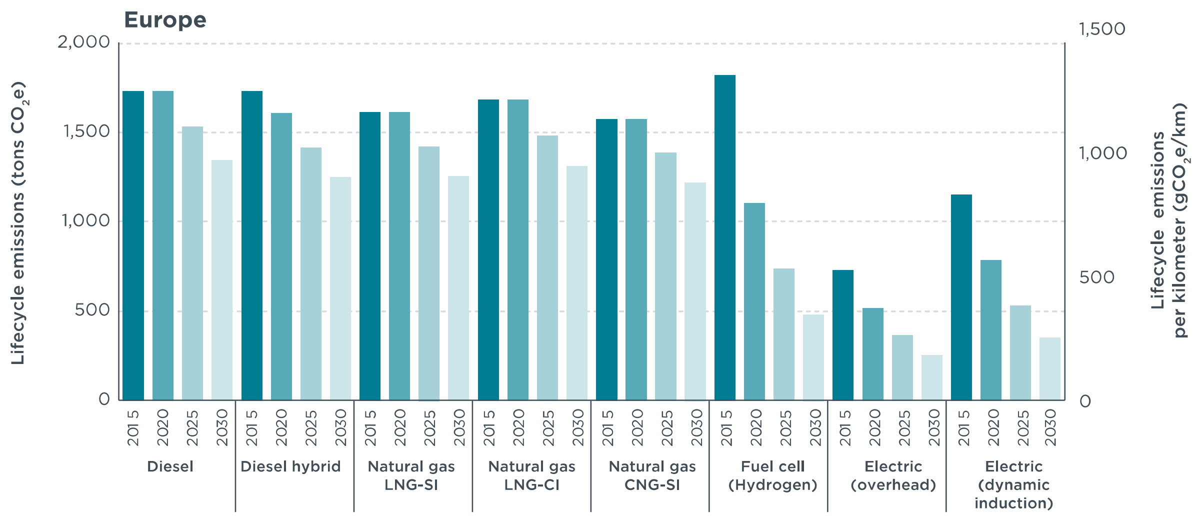


Source: Sharpe (2017).

Policy can have an impact in these situations. Incentives for the adoption of these improvements can be associated with more stringent fuel efficiency and emissions standards. In fact, all of these issues were identified in the expert survey as main barriers to the adoption of more efficient vehicle technologies (see Figure 23 in the next section). The development of intelligent transport systems (ITS) can also help in this regard. These new technologies have the potential to deliver substantial cost savings for companies (see Figure 30), particularly when combined with the role transformation of truck drivers that also imply regulatory changes. Savings achieved this way can cover the initial costs of alternative fuels and efficiency related improvements made necessary by stricter emission standards. They could be a complement to or even remove the need of direct financial incentives.

Given the current state of research and commercial deployment no zero emissions solution in wide-spread use is foreseeable in the short- to medium-term for long-haul heavy freight trucks. Alternatives such as Hydrogen or Electric roads will only be mainstream – if ever - in the mid- to long-term (e.g. 2030 to 2050). Nonetheless, zero emissions alternatives do need to be in general use by 2050 or earlier if climate change targets are to be reached. Each of the mentioned alternatives has different infrastructure and vehicle requirements, but whatever the case the investments will have to be substantial from both private companies (e.g. vehicle manufactures will have to adapt their production process) and public sector (e.g. deployment of distribution and fuelling/charging network). A strategic choice in the type of fuel to scale up for mainstream adoption might be necessary. In this case one or a set of alternatives will need to be prioritised to the detriment of others.

Figure 21. Lifecycle CO_2 emissions by engine-fuel type



Source: Moultak, Lutsey, Beijing, Berlin, and Brussels (2017).

There is a large window of around 20 years from the present until these zero emission solutions will start to have mainstream adoption. This long implementation timetable coupled with the heavy investments required generates some uncertainty. Breakthroughs in other technologies like electric batteries (Earl et al., 2018), advanced biofuels or CCS cannot be ruled out in the next 10-20 years. If they happen these will also come with a cost, but it can be significantly lower than Hydrogen or Electric roads. Furthermore, it is a challenge to have one single alternative to diesel/gasoline for all operation types and areas of the globe. Even if electric roads are a very efficient way to power long-haul heavy operations this solution will not be able to cover all trips. Hydrogen or advanced biofuels could be used as a complement to electric roads on the regions or trip legs that are not covered by the electric road infrastructure. Thus, avenues of research and investment should not be narrowed. There should be room to test new solutions and verify which options work best for different regions and sectors. This implies that policy can play a role of setting emission standards and targets, but taking a "tech neutral" approach on how industry will reach those targets.

Given the different geographic, economic and infrastructure development differences across the world a set of decarbonising solutions seems more suitable than a unique pathway. Ultimately full decarbonisation of road freight means mainstream adoption of a set of options that can be scaled up – at least – to a national or regional level. This means that while further research and tests on a variety of options should proceed in the short term, in the mid-term a strategic policy decision might be required to scale up the most promising options.

Developments in this area are not confined to OECD countries. The case of Brazil discussed above is one example of widespread use of biofuels. The pace at which a country like the People's Republic of China is electrifying mobility and how they are forecasted to take the lead in the production of electric LCVs and being already a major market – if not the larger – in other market segments is another example (J. Coren, 2018), (Bloomberg News, 2018).

Key insights obtained in this section:

- Urban type alternative fuel operations are already a viable commercial solution or will be in the short-term. There is already a business case for electric battery LCVs in cities and in the near future they will be more cost effective than traditional internal combustion engine (ICE) diesel/gasoline engines. Policy should foster the adoption of alternative fuels in cities - e.g. pricing mechanisms, stricter emission standards, total or partial urban zoning restrictions, promoting standards for equipment, supporting recharging infrastructure or adopting alternative fuels for public institutions and large vehicle fleets.

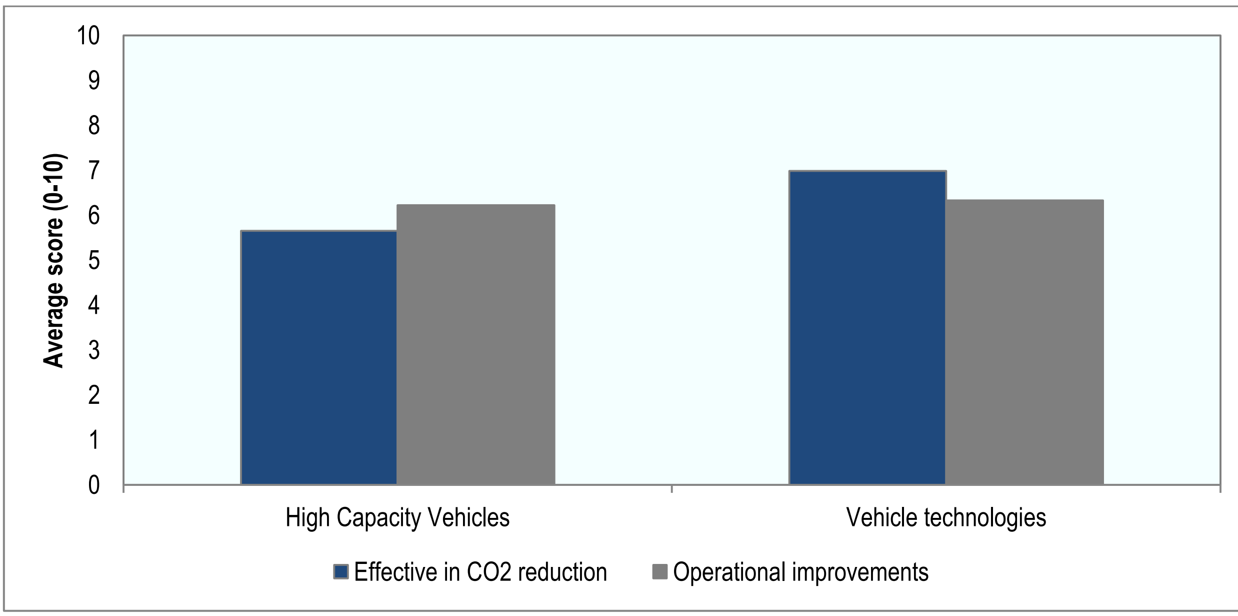
- Commercial alternatives such as biofuels and LNG are already available for long-haul heavy trucks. In some regions these can lead and have led to reduced life cycle emissions. However, these options alone will not reach the Paris agreement targets for climate change and in some cases can even have higher overall life-cycle emissions than diesel engines. Global long-term decarbonising will require other alternatives – or significant advances in these technologies and CCS.
- It is currently foreseeable that technologies such as the direct supply of electric energy to vehicles (electric roads), hydrogen and possibly electric batteries will be able to achieve zero emissions for heavy-duty long-haul trucks - assuming that the electric grids and/or hydrogen supplies are also decarbonised. Hydrogen has the drawback of having very low energy efficiency when produced from electricity or requiring CCS when generated from steam-methane reforming. But it can act as a complement when other more efficient zero emission options are not available. As with other alternatives the production, distribution and refuelling infrastructure has high costs. These can be even higher for electric roads, although this option would be the most energy efficient solution and currently offers the greatest potential in emission savings for heavy-duty trucks. These options can be complementary up to a point, e.g. with electric road systems (ERS) being used to charge batteries.
- It is highly unlikely that one single option will be able to replace ICE diesel or gasoline engines. There is a degree of complementarity between different solutions, e.g. vehicles powered by a direct supply of electricity through catenaries can also have batteries, fuel cells or combustion engines that can run on biofuels. Options that require heavy infrastructure investment might not be available or be less cost-effective compared to other alternatives for different regions. Achieving total or near total decarbonisation involves developing a range of complementary solutions that can be adapted for different regions of the world.
- Strategic policy choices will likely have to be made regarding the set of options to scale up. To reach the mainstream solutions need to be available at national or regional level. The fact that some alternatives can be complementary does not mean they should totally overlap. This is particularly true of the significant investments and recourses that will need to be mobilised to deploy the alternative fuel infrastructure – production, distribution and recharging/refuelling.
- To some extent, trial and error should be allowed and encouraged. Although scaling up solutions implies prioritising, at this stage some flexibility should be considered. There is still some uncertainty associated with the feasibility of widespread adoption of alternative fuels, particularly for long-haul heavy trucks. Many of these technologies and processes are at early stages of development and deployment. Even technologies that have been in use for decades (like overhead catenaries) have not been deployed en mass for this purpose. Even if not foreseeable now, breakthroughs in advanced biofuels, electric batteries or CCS cannot be ruled out.

- Alternative fuels and fuel efficiency improvements need to be attractive for fleet owners. High initial costs can be a deterrent, even when total ownership costs (TOC) are low and payback periods are relatively short.
- Stricter fuel efficiency and emission standards coupled with tax incentives can be policy tools employed to overcome this barrier.

Vehicle efficiency

This section is focused on the contribution of vehicle and engine technologies; particularly for internal combustion engines (ICEs) to decarbonise the sector. Vehicle technologies deliver an array of improvements to vehicles that can reduce their fuel consumption (e.g. adaptations to existing vehicles to reduce aerodynamic and rolling resistance, increased engine efficiency, weight reduction and improved transmission and driveline efficiency). Another logistical option based in technology explored is the wider employment of high capacity vehicles (HCVs).

Figure 22. Rating of vehicle efficiency measures

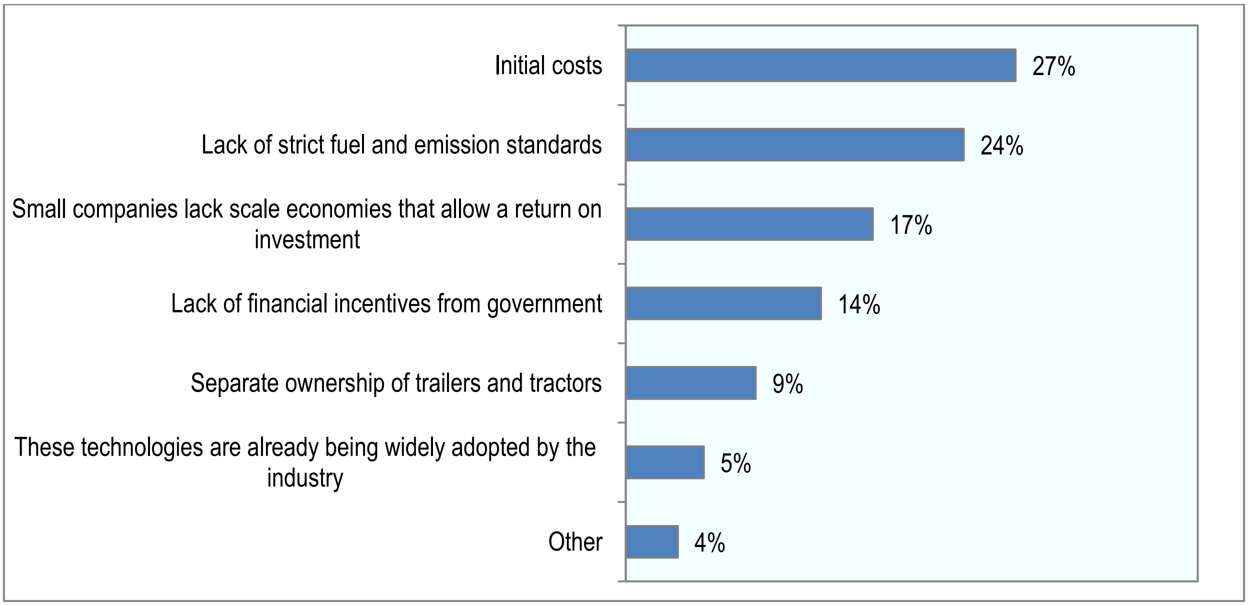


Source: ITF expert opinion survey (2018)

Vehicle technologies were considered the most effective measure of CO_2 emission among other options that the respondents were asked to rate including logistics, intelligent transport systems (ITS) or emerging trends (see Figure 27, note that alternative fuels were not scored in a comparable manner). This is a clear indication that these types of measures and improvements play an important role in the pathway towards Road freight decarbonisation. HCVs achieved a lower rating but are still above average, respondents considered this option would foster more operational improvements than reduce emissions - same as the logistic measures.

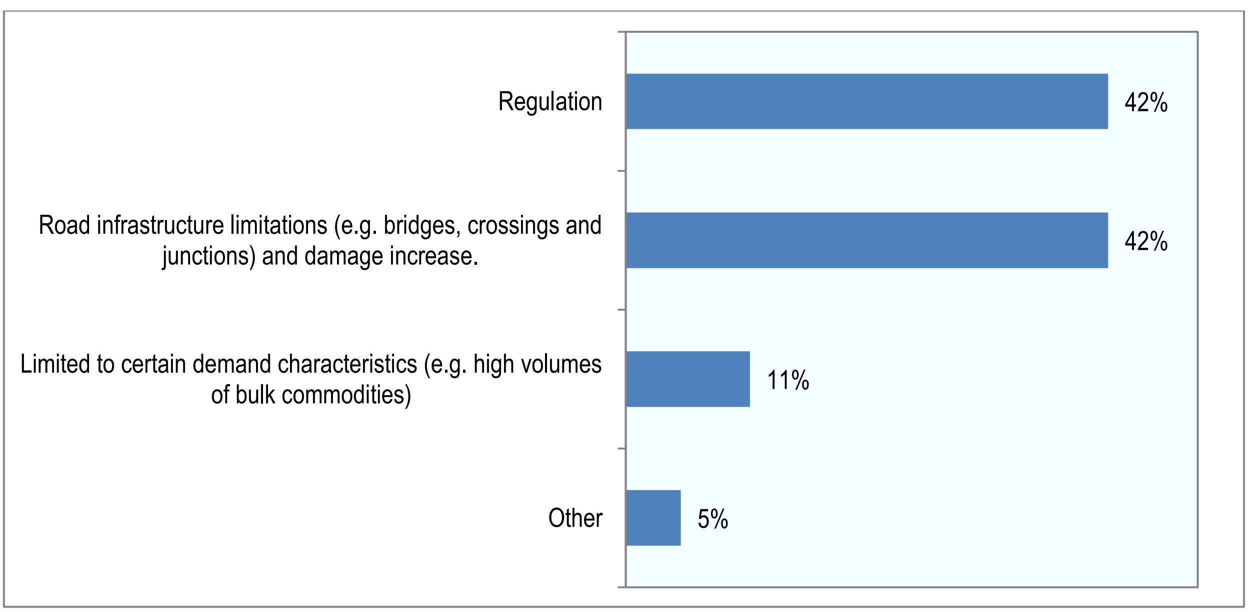
Initial costs were highlighted as the main barrier to scaling up the adoption of vehicle technologies with the potential to decrease emissions. This highlights a wider problem mentioned in the discussion section of the previous chapter. Higher initial costs and risk aversion dissuade companies from these investments even when the total ownership costs (TOCs) are lower and payback periods are short. Addressing this question involves tackling other barriers that ranked high in the survey: lack of strict fuel and emission standards, the lack of incentives (e.g. tax discounts) and understanding that small companies with limited resources play an important role in this market.

Figure 23. Barriers to scale up the adoption of vehicle technologies



Source: ITF expert opinion survey (2018)

Figure 24. Barriers to scale up the adoption of Heavy Capacity Vehicles

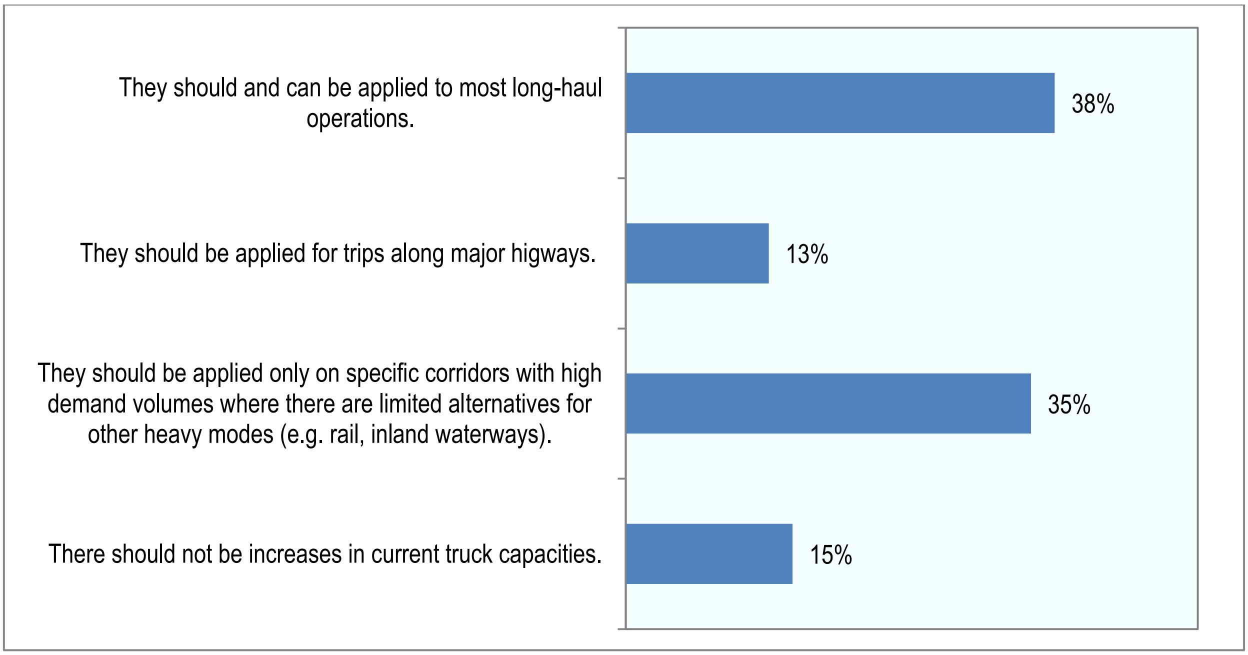


Source: ITF expert opinion survey.(2018)

Regulation and infrastructure limitations are seen as the two major barriers to a more widespread use of HCVs. There are infrastructure elements that do restrain the use of HCVs, but these do not encompass the entire road or highway network. For instance, Finland relaxed the truck size regulations in 2013 allowing HCVs to operate freely on Finnish roads with the exception of certain designated bridges. Another alternative is allowing these vehicles only on specific routes. Infrastructure is not an unsurmountable barrier. Public perception and safety concerns are also invoked, but available data indicates that they can be safer than regular trucks (ITF, 2011).

Only a small minority of respondents (15%) completely rejected increasing current truck sizes and most think there should be some restrictions on their use. Allowing HCVs on specific corridors with high-demand volumes where there are limited alternatives for other heavy modes (e.g. rail, inland waterways) can be the most acceptable way of introducing HCVs.

Figure 25. Extent to which high capacity vehicles should be deployed for long-haul operations



Source: ITF expert opinion survey (2018)

Introducing these type of vehicles can be seen as contradictory to one of the pillars of decarbonising freight – modal shift. Some evidence from the Finnish experience indicates that road freight emissions did decrease since HCVs have been in use (Liimatainen and Nykänen, 2016), although some care is needed since there are only a few years of experience. Other studies on Nordic countries corroborate to the emission saving potential of this measure, but under certain scenarios when modal shift from rail to road is too high there are increases in emissions (Pålsson and Sternberg, 2018). In fact, the most recent data from Finland does point to a loss of modal share from rail and increase of road (Eurostat, 2016b). But these fluctuations also happened in the past and there is no conclusive evidence that HCVs were the cause.

Another issue to consider are the rebound effects on demand. Further lowering the costs of transportation either through improved vehicle efficiency or logistics can stimulate demand growth. This can offset emission savings from increased efficiency (Dimitropoulosi, Oueslatii, and Sintek, 2016).

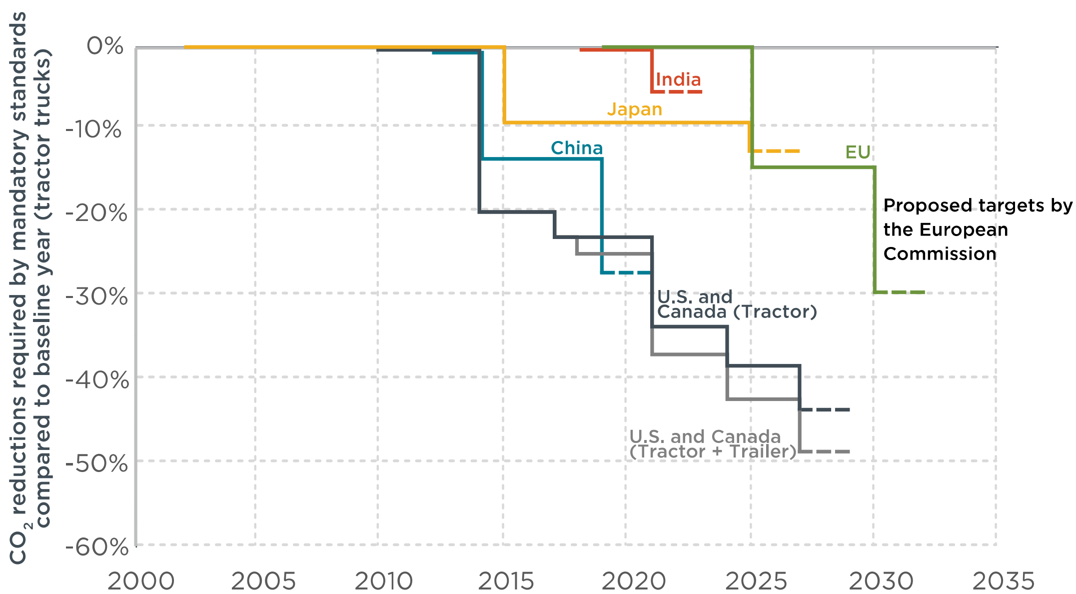
Presentation summaries

Fuel efficiency technologies for heavy-duty vehicles

The International Council on Clean Technology (ICCT) has been conducting research directed at quantifying the potential CO_2 emission savings and fuel consumption reduction of different technologies that can be applied to internal combustion engine (ICE) diesel heavy trucks. This work was developed in the context of the recently issued proposal of the European Commission for heavy-duty vehicles CO2 emission standards.

Strong regulatory measures to introduce CO_2 emission standards for heavy-duty vehicles have been gaining ground across the world, although they still lag when compared with private car regulations. In the United States and Canada the reduction target is close to 50% for tractors and trailers by 2027. These standards have been adopted because vehicle technology adoption rates have not been fast enough to meet climate change targets. There is to some extent a "market failure" with technologies available in the market for several years not being widely adopted even when they deliver positive net present values (NPVs), a situation widely discussed above in this report.

Figure 26. Long-haul tractor-truck CO_2 standards around the globe



Source: International Council on Clean Transportation (2018).

Decreasing the carbon content of the fuel mix necessary to move goods is one of the options to reduce emissions and the only option that can ultimately achieve full decarbonisation of road freight. Of the available technologies direct supply of electricity (electric roads) delivers the lowest lifecycle CO_2 emissions (see Figure 21). But these alternatives will only become available in the long term. The most important measures that can reduce emissions in the short to medium-term are related to vehicle technologies that can increase efficiency of ICE vehicles.

The emissions savings potential by 2030 was assessed by comparing a 2015 reference tractor trailer to vehicles equipped with different technology packages available in this time frame. Vehicle simulation tools were employed to measure performance under different vehicle specifications. Parameters that had a significant impact in emissions included engine peak efficiency (which provided most of the gains), aerodynamic drag, reducing gross vehicle weight (or light weighting) and introducing hybrid powertrains. The results indicate that by 2030 it would be possible to reduce fuel consumption by 43% (Delgado et al., 2017).

These technologies would increase the tractor-trailer costs by 20% or around EUR 30 000 – EUR 40 000 (Meszler, Delgado, Rodríguez, and Muncrief, 2018). This assumes increasing economies of scale and manufacturing learning curves that would decrease costs for the technologies employed in the "new tractor trailer" of 2030. There would be a payback period between 1.4 and 2.7 years for this technology package, below a three year reference payback period for truck operators.

High capacity vehicles

The International Transport Forum (ITF) is conducting a workgroup to update state-of-the-art ITS measures for a more widespread introduction of high capacity vehicles (HCVs) and further the discussions from the previous report (ITF, 2011). The countries that first initiated this common interest group are Sweden, Finland, Denmark, Australia and Norway. There are also participants from South Africa, New Zealand, the United States, France, the People's Republic of China and the United Kingdom.

The project aims to respond to community demands for improved road safety and environmental sustainability as well as social and economic needs for increased productivity. The expected outcome is a broad global picture of the use of HCVs - which type of transports and vehicle combinations, trends and ongoing research and development as well as regulatory framework, strategies and road maps in different countries. The project provides guidance for policy makers on fundamental principles for the development of an adequate regulatory framework for countries interested in relaxing the weight and dimensional limits of trucks and implementing the HCV concept.

High Capacity Vehicles are a solution available today that can reduce fuel consumption per unit of transported cargo, hence CO_2 emissions per tonne-km moved. For example, a Canadian B-train HCV emissions per tonne-km are only 60% of a semi-tractor from the United States. HCVs have also been proven to be safer than standard heavy trucks with reported accident rates in all countries being lower for HCVs. These larger trucks are generally equipped with additional safety systems and companies assign their best drivers to them. They also tend to be limited to specific geographical areas which can bias this comparison. Their higher efficiency also means that less vehicle kilometres are needed to move the same amount of goods which decreases opportunities for accidents to occur. The ability to move the same tonnes with less vehicle kilometres also means reduced transport costs. Even though capital costs of these trucks are higher, variable costs such as fuel and labour will decrease and the latter represents a larger share of the cost structure - around 65% in a European context.

Regulation has been the major barrier to the adoption of HCVs. New Intelligent Transport System (ITS) features can offer added assurances regarding safety and other concerns that can lead to greater societal acceptance. The regulatory framework that enables the use of HCVs can include several safeguards like additional requirements on vehicle performance, drivers' qualifications or limits to the road network that these types of vehicles can use. Limiting HCVs to certain origin-destination (OD) commodity pairs where there are no alternative heavy modes can offer a pathway for more widespread use.

Lower-carbon combustion engine technologies

A cornerstone of Aramco's research approach is to take an holistic view on fuel and engine design, two areas that are closely related but have not been optimised together. A technology currently being tested is heavy duty Gasoline Compression Ignition (GCI), using gasoline as an alternative fuel for diesel engines.

This has the potential of combining the lower carbon content of gasoline with diesel's higher efficiency. A conventional heavy-duty diesel engine common in North America has been used to run on gasoline with a few adaptations. Aramco's results show that with a specially designed highly reactive gasoline there can be up to a 7% decrease in CO_2 emissions compared to a standard diesel engine, while maintaining a similar brake thermal efficiency. Using current gasoline with minor tweaks to the diesel engine can deliver a 3% reduction. One benefit of these options is that they take advantage of existing fuel production, distribution and re-fuelling infrastructure.

Another project looks at reducing heavy-truck carbon emissions by 50%, which include a number of technologies such as in-vehicle mobile carbon capture. Increased engine efficiency can save around 5%, less friction from 1- 3% and waste heat recovery about 2-3%. These options that are also considered in the "SuperTruck" initiative are in the single-digit savings range. It is estimated by Aramco's research that mobile carbon capture could reach 40%-50% reductions. A passenger vehicle prototype was already presented, but this technology has greater potential on larger engines and vehicles. A class 8 truck prototype is being developed with a 40% carbon capture target. The on-board carbon storage tanks have a significant volume – three tanks totalling around 850 litres – but given the vehicle size it is considered a feasible option by the project engineers. This demonstration truck, equipped with gasoline compression ignition (GCI), carbon capture on-board and other technologies (waste heat recovery, low rolling resistance tyres and lubricants-reduced friction), can theoretically achieve between 55% to 59% CO_2 savings. The truck should be ready for public demonstrations by the end of next year. The target for the real life prototype is 50% emission decrease compared to the baseline vehicle.

Discussion

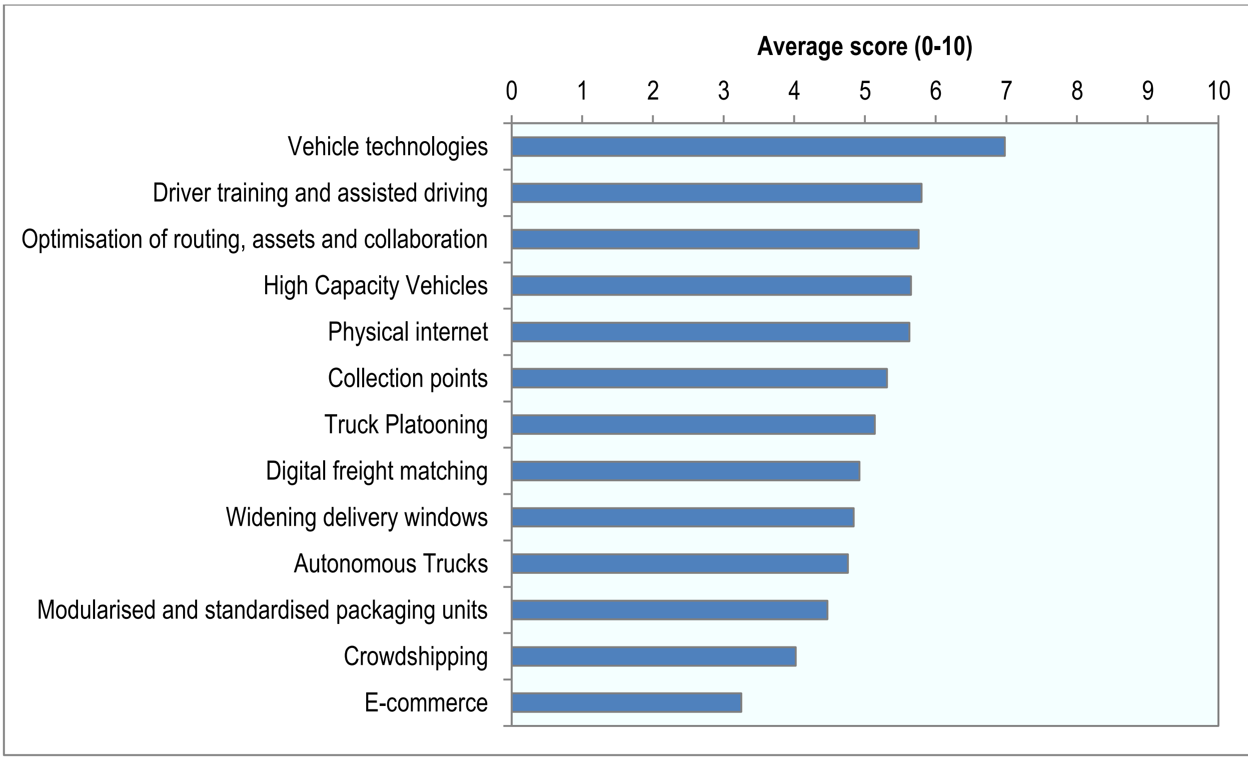
Technologies that can improve the fuel efficiency of diesel heavy vehicles are a fundamental component of a pathway towards decarbonising road freight. In the short- to medium-term this is where a significant part of emissions savings can be delivered, particularly for heavy trucks on long-haul operations. Logistic changes have great potential but until now that potential has not been met. Alternative fuels are a promising prospect for some operation types in the short term, but a significant impact on the bulk of emissions coming from the long-haul will only take place at best on a 20-30 years horizon. Right now there is already available equipment – including retrofits for existing vehicles – that can increase vehicle efficiency. The expert opinion survey respondents considered this measure the most effective way to reduce CO_2 emissions (see Figure 27, note that alternative fuels results in the survey are not comparable).

High capacity vehicles are a tested technology that has the potential of lowering emissions, congestion and overall transportation costs, while increasing safety. But there are also caveats. As with other cost saving measures it can have a rebound effect on demand. If there is reverse modal shift from rail to road above a certain threshold the impact on emissions will be negative. There are also concerns regarding pavement degradation and risk to bridges. The ITF has a working group researching this topic which is related to studies being developed by Centre for Effective Dispute Resolution (CEDR). What research has shown is that HCVs per tonne-km can actually have fewer impacts on pavement degradation. There is a problem on certain bridges – which will also affect truck platoons if they are in general use – but these are very specific segments of the network. Introducing these types of vehicles with higher performance and safety requirements, on a limited number of corridors where there is no heavy mode alternatives can be a pathway for increased political and social acceptability of HCVs.

There are some promising early results from technologies like mobile carbon capture for heavy-duty vehicles, but further research is still needed. Mainly into the wider societal question of how to dispose or sequester the carbon captured by these technologies. As mentioned carbon capture and storage (CCS) is not a mature technology and there has even been some steps backwards (The Guardian, 2015), but future developments should not be ruled out.

The United States and Canada have the most stringent standards regarding heavy-duty trucks, more than the EU who is generally considered a leader in green tech and policy. The difference is that in Europe similar emission standards will be applied to all vehicle types, whereas in the United States they are particularly stringent for trucks.

Figure 27. Measures effectiveness to reduce CO_2 emissions



Source: ITF expert opinion survey (2018).

Heavy-duty vehicles have more effectively reduced their air pollutants emissions than light vehicles. It is a fact that these larger vehicles have more available space; hence it is easier to apply after-treatment emission control technologies. But the critical reason why they have been more effective in this field is regulation which has been more stringent than for light vehicles– at least in the United States.

There has been growing concern about air pollution particularly in urban environments. Policies to decrease pollutants can have a positive impact on CO_2 emissions, particularly in cities where electrification is promoted and restrictions are placed on diesel engines. Stricter pollutants standards can also impair fuel efficiency and cut into potential CO_2 emissions savings; this might be one of the reasons why some institutions argue that vehicle efficiency has been flat in Europe for the last 10-15 years (e.g. ICCT or T&E). Although preliminary analysis indicates that the latest generation of Euro VI engines do perform better in terms of CO_2 emissions and fuel consumption.

Natural gas compared to an average diesel truck has less particulate matter (PM) and nitrogen oxide (NOx) emissions due to these fuels lower combustion temperature. But this is not the case for the most recent Euro VI diesel trucks where there is no significant difference between Gas and Diesel standards, if anything they are more stringent for Diesel regarding PN.

The recent emission scandal involving light duty diesel engines places added value on the reliability and accuracy of measurements and estimates. Having reliable, accurate emissions data and estimate potential savings from different technologies is of paramount importance. Harmonising the methodology to measure emissions across Europe, North America and the People's Republic of China would be a step forward. There are regional specificities that need to be taken into account (e.g. mission profiles, payloads) but the methodology itself can be the same. Different simulation tools can be used to calculate the emissions (e.g. VECTO, GEM or Autonomie); a critical aspect is to use the same methods to collect the parameters of these simulations (e.g. drag, tire rolling resistance). When estimating the impact of future technology packages for trucks it is also critical to input realistic parameter values to obtain convincing CO_2 savings assessments.

Key insights obtained in this section:

- Improvement of vehicle efficiency through technology is one of the most cost-effective ways to reduce emissions. It is a fundamental element on the pathway to road freight decarbonising.
- CO2 emissions standards and regulations are necessary to foster the wide-spread deployment of greater fuel efficiency solutions.
- Mainstream adoption of new technologies is made easier when there is a solid business case. These vehicle technologies need to be attractive to fleet owners. Return on investment, payback periods and risk need to be equal or more advantageous than traditional solutions. High initial costs are an important barrier that needs to be mitigated.
- High Capacity Vehicles (HCVs) are a tried and tested cost effective solution to decarbonising road freight. HCVs can operate on specific corridors where there are no infrastructure barriers (e.g. avoid certain bridges) and no alternatives for heavy modes. For these types of trucks the safety and efficiency standards should be more stringent than for regular size heavy trucks - as is already the case in most places HCVs operate.
- Evidence-based decisions require accurate, reliable data collection and realistic parameters to estimate potential impacts of new solutions. Global harmonisation of methodologies to measure emissions would facilitate the spread of new technologies.
- There are many examples of technical solutions that have been tried and tested and can already be deployed. Other newer solutions might deliver promising savings (e.g. mobile carbon capture), but they require further research on the vehicle technology itself and disposal of the captured carbon - there is no tried and tested method to do it and there has been some setbacks in recent years.

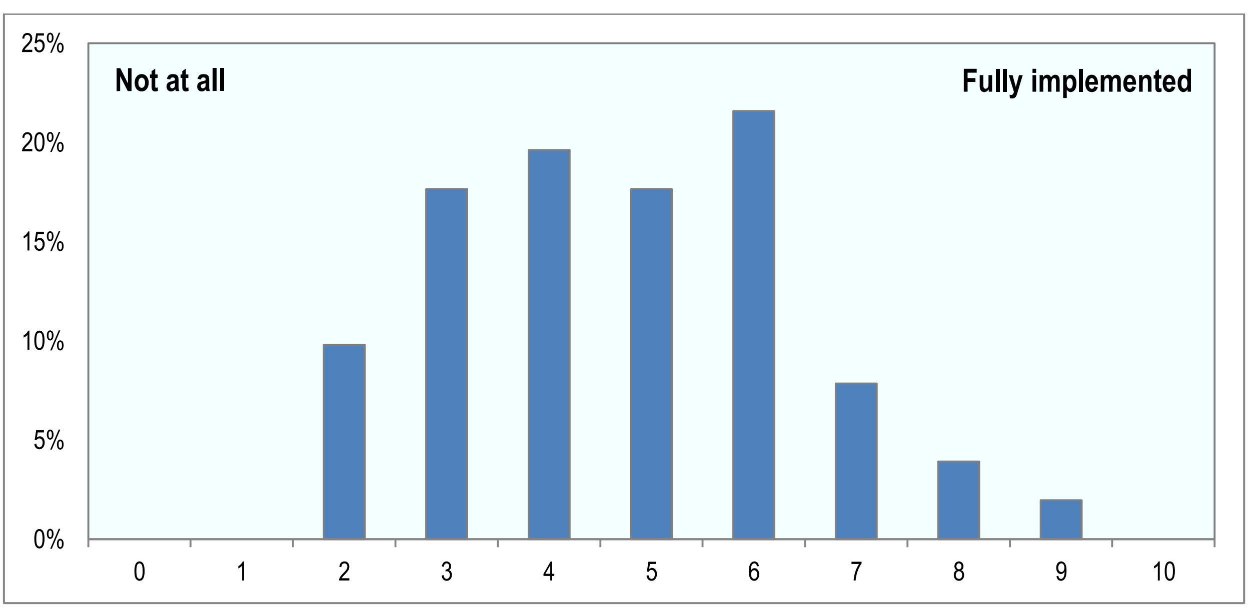
Intelligent systems and eco-driving

The focus of this chapter is on eco-driving and intelligent transport systems (ITS). The latter include advanced assisted driving systems (e.g. adaptive cruise control, real-time fuel consumption monitors that also suggests modifications to driving behaviour) and in vehicle–to-vehicle communication systems that can be used to set up semi-automated vehicle columns (truck platooning). To its maximum extent intelligent systems combining a wide range of data and algorithms (e.g. sensor data, GPS, communication between vehicles and vehicles to infrastructure) can lead to fully digitalised autonomous trucks (or driverless trucks).

Driver training and assisted driving (also mentioned as eco-driving) is one of the most effective ways of reducing emissions. This is shown in the results of the expert opinion survey where this measure achieved the second highest ratings (see Figure 27, again note that these measures do not include alternative fuels). Eco-driving training has already been in use and the records show it saves emissions. It also has low adoption barriers making it one of the most obvious “low hanging fruits” for decarbonising road freight.

Truck platooning does have the potential to decrease the drag of vehicles closely packed in a column, hence increasing fuel efficiency. But its benefits are more associated with the reduction of operational costs. The contribution of autonomous trucks towards decarbonisation is less clear. They might increase driving efficiency, have more loading space and avoid congestion by using “off peak” periods, but they were one of the measures that ranked lower in the effectiveness of reducing CO_2 emissions.

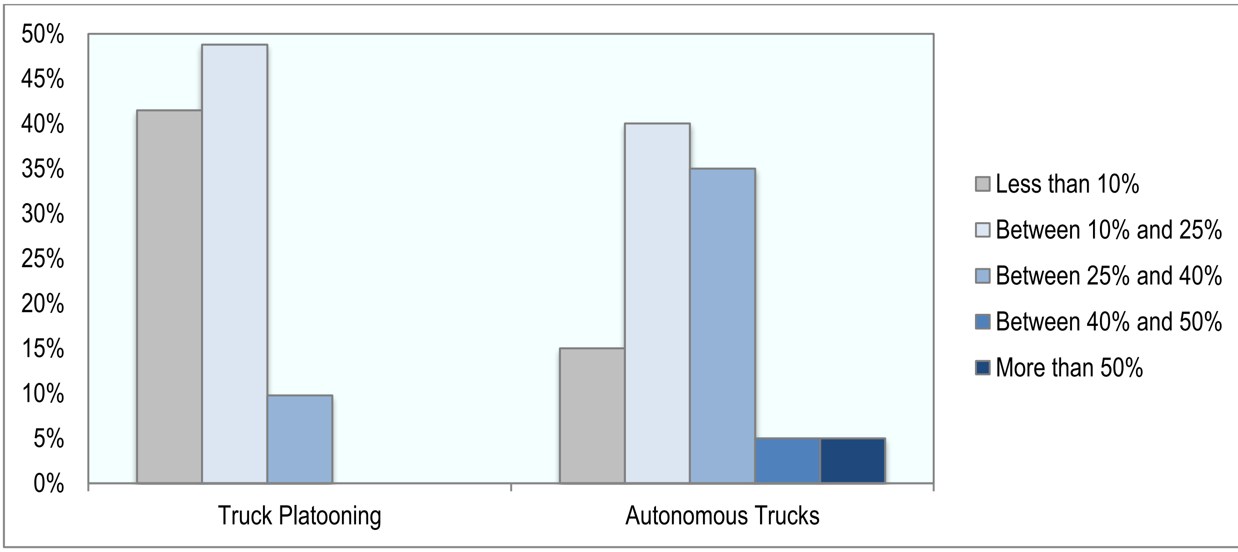
Figure 28. Extent of driver training and assisted driving currently employed across the industry



Source: ITF expert opinion survey (2018)

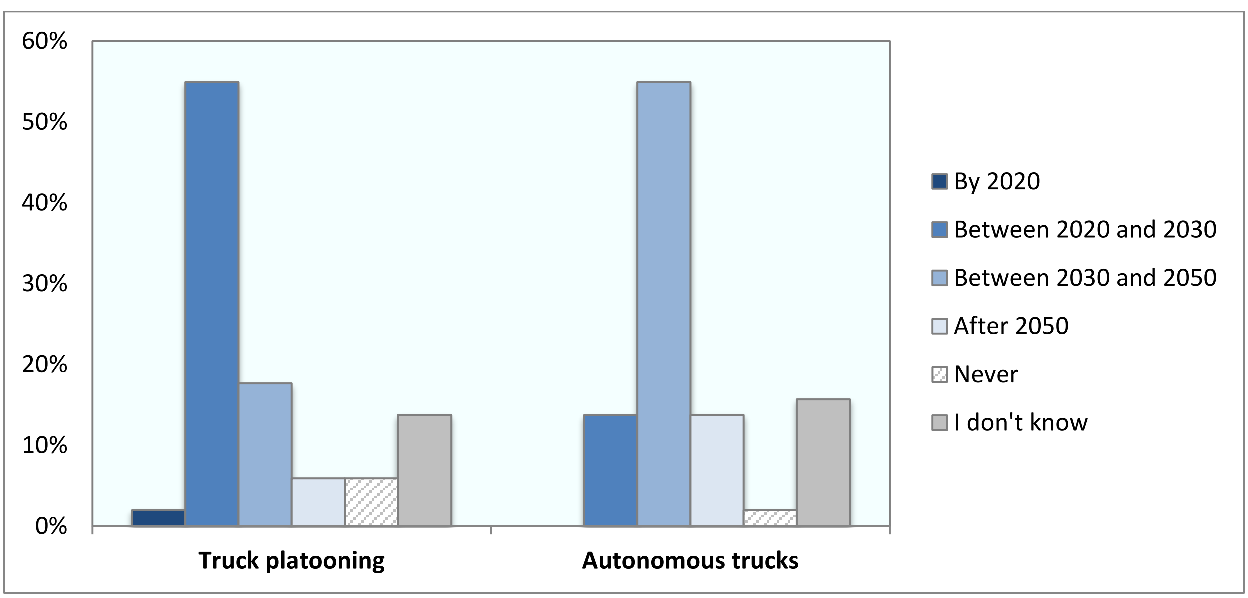
Since driver training is one of the most important “low hanging fruits”, it is relevant to know to what extent it can be further employed. The survey results indicate that this measure is already used to some extent, but there is still margin to expand it.

Figure 29. Best estimate for the operational cost decreases by trip (or vehicle-km)



Source: ITF expert opinion survey (2018).

Figure 30. When will autonomous trucks be in general use?

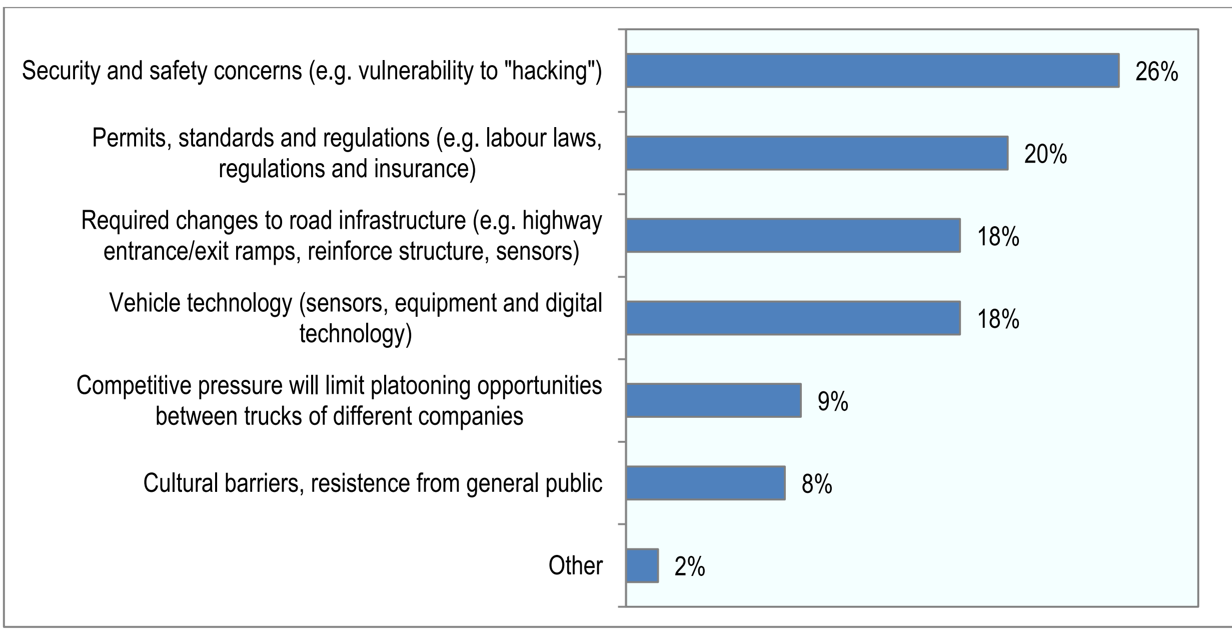


Source: ITF expert opinion survey (2018).

Truck platooning and autonomous trucks can bring significant cost savings. Most respondents considered that platooning would reduce costs by at least 10%. The potential of autonomous vehicles is even greater with almost half the respondents stating this would decrease costs by more than 25%. In fact, labour accounts for 25% to 45% of road haulier cost structure. The ability to decrease or totally remove labour costs, plus a more flexible use of the vehicles - no mandatory stops for drivers to rest and other limitations on driving periods – can indeed significantly cut costs. It is also a measure that can address the emerging shortage of professional drivers faced by the haulage industry, this issue was extensively discussed by ITF (2017b).

This significant potential to cut costs opens both challenges and opportunities for decarbonising the sector. The higher returns obtained by the industry can be reinvested in increased efficiency and alternative fuel technologies. This can be one option to overcome the high initial cost barrier of some of these technologies. Nonetheless, a dramatic decrease in costs can also lead to important increases in demand that can offset any efficiency gains. Policy can play a decisive role in solving this dilemma, e.g. by imposing stringent emission standards for these vehicles. These might be similar to non-autonomous trucks in early adoption and research stages, but the industry should be made aware that the vehicles for main stream adoption should comply with higher emission standards than what current regulation envisions.

Figure 31. Major barriers to the uptake of truck platooning

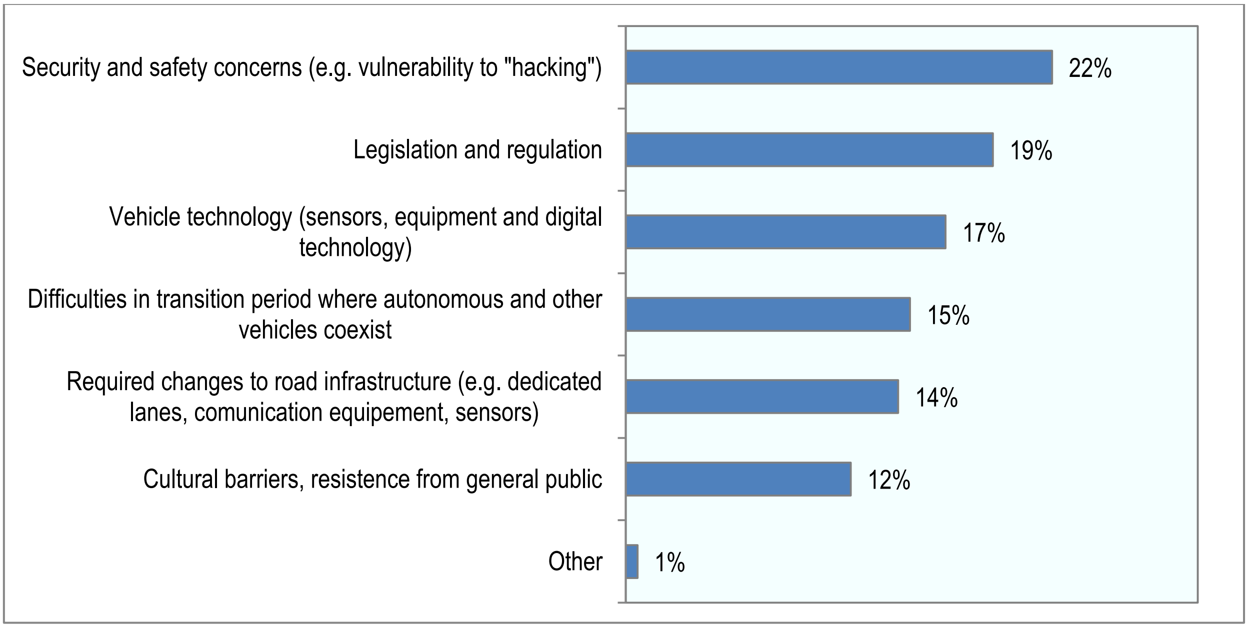


Source: ITF expert opinion survey (2018).

More than half of the respondents stated that Truck platooning will be common practice by 2030. As for Autonomous vehicles, survey results indicate they will be in general use by 2050. There have been already several trials with digitally connected truck platoons (Dutch Ministry of Infrastructure and the Environment, 2016; CEDR, 2016 and RDW, 2016) and autonomous vehicles are already in operation in very delimited and controlled environments like ports and mines. Nonetheless, there are still open questions regarding to what extent both these systems will be deployed.

Safety and security concerns were considered the main barrier to the widespread adoption of these systems. The second obstacle was standards and regulation. The need for further development in vehicle technologies and adaptations to infrastructure also ranked high in the barriers. There are still technological barriers to overcome in the deployment of both these systems – outside trials and very controlled spaces. Trials with truck platoons still have the vehicles driving at distances that do not significantly reduce their drag. Truck platooning can move quickly into commercial use, but at a first stage it will be hard to capitalise on their full promise (e.g. more fuel efficiency and decrease the need for drivers).

Figure 32. Major barriers to the uptake of autonomous trucks



Source: ITF expert opinion survey (2018).

In part the barriers to platooning are of a managerial and social nature. There are still issues concerning the business model, insurances and safety concerns from the public. For truck platooning to be commercially attractive it requires a revision of driver's working and rest regulations. These regulatory revisions rely on government oversight of developments in this field.

There are different levels of driving automation - see ITF (2017b) - and it is not clear that fully driverless trucks (or full automation level 5) will be possible for all road freight operations. But it is certain that vehicles will be equipped with systems that will increasingly assist driving. As for truck platooning the business case for increased automation is based on relaxing driver regulations due to reduced workloads. Driverless trucks connecting logistical depots along highways are predicted to be the first market where full automation will be deployed for Road Freight operations. This is likely to happen in the medium-term, but probably not within the next 10-20 years.

Presentation summaries

Fuel efficiency training

The International Road Transport Union (IRU) provides an example of eco-driving courses offered to professional drivers. The courses focus on increasing the drivers' road awareness and how their driving style can affect vehicle efficiency and safety without increasing trip times. Eco-driving lowers fuel consumption and CO_2 emissions, but also results in lower maintenance costs, less damage on goods transported and improved road safety. This is a measure with a strong business case and it can increase fuel efficiency by up to 15%. The IRU's "30-BY-30" resolution on a voluntary contribution of the road transport industry to reduce CO_2 emissions by 30% by 2030 provides the background for these efforts.

Two specific cases were explored in Poland and Romania. In both cases the training results were obtained over 14-15 months, where the training trips covered all kind of road circumstances. The average reduction in fuel consumption on these trainings was respectively 12.24% and 9.24%. This is comparably higher than other more resource intensive and costly measures. Since fuel costs alone can be about 20%-35% of road transport operations, this level of fuel savings can be of significant value for a company's budget. Evidence from the companies showed that the results obtained in the training translated into their "real world" operations with important savings indeed taking place. These fuel savings are directly correlated with less CO_2 emissions.

In order to obtain sustained outcomes it is necessary to continuously monitor results and engage with the drivers. Prizes and incentives also play an important role in motivating drivers to perform better and maintain the levels of proficiency acquired after training. Some of the companies that participate in this program do offer incentives for their drivers.

It is mainly large companies who have participated in these courses as they have the resources to invest in eco-driving. These resources are not only financial, but also time and availability. In small family or one person businesses even though there is no formal training there is a strong cost incentive to adopt the best practices of eco-driving – e.g. checking tyre pressure, driving at steady speed, accelerate and brake smoothly, closing windows at high speed and minimising use of heating and air conditioning.

A large company like GEODIS has been practicing eco-driving for 20 years now. In addition to driver training trucks have on-board equipment that monitors and provides feedback to drivers to improve their behaviour – e.g. use of gears, engine breaking or anticipation. Studies show that on average eco-driving coupled with on-board ITS applications lead to an average of 10% reduction in fuel consumption (for mixed roads). These savings are especially high at junctions, traffic lights and bends where they can reach 25%. There are little or no benefits in congested situations and limited benefits on motorways.

This is a measure which has been in use for some time now and has proven its effectiveness. But there is still room to increase its benefits, particularly by extending it further to mid and small size companies.

Potential of intelligent transport systems to reduce emissions

Intelligent transport systems (ITS) encompass a wide array of technologies that can contribute to the reduction of greenhouse gas emissions in road freight transport. In 2016 Ertico published a wide ranging study in conjunction with ACEA (Winder, 2016) that looked at real, simulated and modelled results for heavy commercial vehicles (trucks and buses) from ITS applications that can potentially reduce emissions from vehicles. These applications include in-vehicle devices influencing navigation and driving dynamics. They can also be infrastructure based and cooperative like traffic management systems and auxiliaries for parking and deliveries.

Eco-navigation provides up-to-date traffic information and proposes the most fuel efficient routes by avoiding congestion, steep ramps or junctions. Because it optimises fuel consumption – not the time – it can result in longer trip times. It is most effective for urban and suburban areas where fuel consumption can be reduced by 5%-10%. It has less impact on long-haul operations on highways. Predictive powertrain control focuses on topographic data to generate a predictive speed profile to optimise control of the powertrain. Applications in the market deliver average savings of fuel by 5%. Cooperative-Adaptive Cruise Control (C-ACC) is an enhancement to ACC systems that interacts with other vehicles and/or infrastructure to optimise the vehicle speed profile. Tests on trucks showed a 2% reduction in fuel consumption.

Truck breaking and starting has a higher impact on emissions than a car. Prioritising the smooth flow of heavy vehicles in cities (selective truck priority) by employing traffic signal control can save emissions. Projects measuring the impact of these measures in test sites on cities (Helmond and Lyon) found that emissions were reduced by 8% to 13%. An energy efficient intersection service is a similar initiative where the green phase of traffic lights is extended for selected vehicles. Measurements on test sites showed decreases of 5%- 10% in CO_2 emissions (g/km) at the intersections. Intelligent truck parking and delivery space booking allow on-trip reservation for loading spaces in cities and truck parking on motorways. This results in about 20% savings at the delivery/parking location.

Overall the impacts of ITS depend on several factors. The type of road network and operation type (e.g. urban delivery or motorway transport), the topography, driver behaviour and penetration rate of these systems. Moreover there was no combined assessment of these technologies. Some have overlapping effects while others can be added up. For instance, more efficient vehicles will decrease the margin by which eco-driving can decrease emissions. A future task is to explore and build a consensus on a method to measure the combined effects of different ITS applications. In addition there should be a common impact assessment methodology to evaluate in a comparable ways different solutions for reducing emissions.

Discussion

The road freight sector has features that make it suitable for early adoption of fully automated vehicles. There are great savings on labour costs (around a third or more of the operating costs in Europe and North America) and a strong commercial incentive to apply automation in trucking. A part of the operations takes place in highways where automation will be easier to implement than in a more "chaotic" urban setting. Driverless trucks will be able to operate 24 hours per day, increasing the use per asset, making it easier to avoid peak hours and providing greater flexibility in fleet management. This is an aspect that should be taken into consideration in the mid- to long-term debate about alternative fuels, namely the time taken to refuel/recharge the vehicles.

However, there are also important barriers to driverless trucks. Further developments in vehicle-to-everything (V2X) communication and standardisation are needed. Current consensus indicates that we will in fact have driverless trucks but that will only happen in a 10-20 years' timeframe and it will happen on specific highway corridors between logistic centres with large volumes of demand. Road freight is ahead of other sectors in this field, but other markets also show great potential like public transport where several trials have taken place and services are already operating in cities (ITF, 2018c).

Meanwhile, drivers will keep playing a central role in this industry, but their profile is changing. Even without level 5 full-automation a range of ITS applications are already in use, including assisted driving. In a semi-autonomous vehicle the driver has different role. The task of driving a truck will demand less direct control of the vehicle and will shift more towards vehicle monitoring and that of a freight manager. Current drivers actually welcome the adoption of new systems that make their task smoother. In the short- and medium-term this means that the type of candidates and skill sets required of future drivers will change.

A shortage of drivers poses an important challenge to the industry and this shortage will be felt before fully automated vehicles are in general use. At this moment it is important simply to keep existing drivers, particularly those that have specialised training (e.g. eco-driving). Going into the future the evolving role of truck drivers and improved on-board conditions might actually help the industry to attract more candidates for the task of freight managers/monitors – even the cultural image of the truck driver will probably change. Governments should keep close attention to these trends in the industry. Driver regulations needs to be updated as their role behind the wheels decreases and the tasks behind the screens increases.

Eco-driving does not necessarily imply slower driving, but it does mean steadier driving and lower consumption. It also implies more defensive driving and increased road safety. Having public recognition of eco-driving for both vehicles and drivers is important to increase awareness of other drivers sharing the roads and it is also an incentive for truckers and companies that implement this measure. Eco-navigation and eco-driving in an urban environment can reduce road capacity and increase congestion, this will not happen in rural suburban areas and highways.

The growing relevance of ITS applications in trucks will lead to new challenges. One of them is cybersecurity. In the medium- to long-run there are some questions surrounding the usefulness of these systems. For instance, as vehicle equipment and efficiency improves the impacts of eco-driving decrease. Moreover, do all these fuel saving applications actually make sense for electric vehicles? These are issues that might come in the long run, but right now both eco-driving and ITS fuel saving applications are very effective ways to cut emissions. Even if all trucks are electric, energy will still be a finite resource, so measures that can save it are important. In addition, eco-driving and ITS can increase operational performance and safety so they will always be useful. If anything, issues like avoiding congestion and increasing safety will have a greater weight in the efforts to optimise driving profiles than saving energy.

Key insights obtained in this section:

- Eco-driving is one of the most effective measures to save CO2 emissions and is a great example of a “low hanging fruit”. Whilst several large companies have adopted this practice it needs to become more accessible for mid- and small-sized companies. Prizes and other type of incentives matter; public recognition of companies and drivers partaking in eco-driving are examples of this. This raises awareness in society, motivates those already in these programs and nudges industry agents to join in.

- Increasing vehicle automation and driver assistance is a reality, even if full automation is a longer term perspective limited to certain markets. The role of the truck driver is shifting. It will increasingly play a managing and monitoring role, while decreasing direct control requirements. Governments and driver regulation should accompany these changes. The evolving working conditions and skill set of the labor employed in the trucking industry might be used as leverage to attract more candidates and attenuate the driver shortage. This is also a development that might influence the characteristics – namely refueling/recharging times – of alternative fuels.

- Full automation and even increased levels of automation including the ability to have digitally connected truck platoons can deliver significant cost savings. These can be mobilised to invest in more fuel efficient vehicles and adopt alternative fuels. But it can also lead to increases in demand that would offset any emission reduction from increases in efficiency. Policy plays a role here. Companies should have returns from their investments in automation but higher emission standards for these vehicles would also help direct investments towards decarbonising road freight.

The role of infrastructure

Infrastructure changes and investments will be required in association with all non-drop-in alternative fuels, new vehicle technologies and the drive towards automation. The majority of alternative fuels require new distribution networks and refuelling or recharging stations. Autonomous vehicles and ITS development require increased data connectivity and information from the roads. This means more sensors and communication equipment on the infrastructure. In addition, changes to highways entry/exit ramps, dedicated lanes and other adjustments might be required for the widespread use of truck platooning and fully automated vehicles. A more generalised use of HCVs might also imply reinforcing certain segments of the network, e.g. bridges. Deploying less rolling resistance pavements is a straightforward way in which infrastructure can contribute to decrease emissions from road freight (Transport and Mobility Leuven, 2018). All of these bring challenges for infrastructure supply and management, including its funding, maintenance and increased scope of action.

Electric roads systems are one of the technological pathways towards road freight decarbonisation directly associated with infrastructure supply. Some of its features were already addressed in the Alternative fuels and Fuel efficiency sections of this report. We will look at this option in more detail below.

Presentation summaries

Low carbon road operation: Electric road systems

Electric roads consist of the direct supply of electric energy to the vehicles while on motorways. This can be assured by overhead catenary, ground conductive or inductive solutions. Trucks do not necessarily need to be always receiving a direct supply of electricity to be in operation. They can be equipped with batteries, hydrogen fuel cells or other options that power the engine when driving outside the direct supply system – although at least 20% and preferably 50% of the annual distance driven should be on an electric road.

Electric road systems (ERS) offer the most energy efficient solution for trucks when compared to diesel and other alternatives like hydrogen or gas. As noted in the chapter on Alternative fuels one-third of the total costs come from fuel. So any efficiency advantage has a big impact on the bottom-line. It is also the option that currently reduces the most CO_2 emissions (e.g. see Figure 21). Given the high costs and long-term nature of this investment electric roads are more suitable for trunks highways where there are high demand volumes. Operations using electric roads would have shuttle like elements with heavy trucks on electric roads travelling between major centres of demand generation/consumption (e.g. distribution centres, ports, terminals).

The installation and maintenance costs are the major obstacle to this alternative. This relates to the business model and regulatory framework that needs to be set up. On the technical side there are still safety issues, and standards that need to be adopted that will ensure the same technology will be used at least at a regional level (e.g. across Europe). A critical aspect to take into consideration is the increased electricity demand on the grid. Though this system is less demanding of the electrical grid than recharging electric batteries because it allows for a smother load profile, especially when compared to "mega charging" or extreme fast charging (XFC).

There are several on-going trials with these systems already implemented on stretches of highways and being used by freight trucks, namely in Sweden and the United States. The number and scale of real world trials is set to expand in the coming years (e.g. Germany and Italy).

Figure 33. Potential impacts of Electric Road Systems according to stakeholders (%)

Impact	Significant adverse impact	Adverse impact	No impact	Minimal benefit	Significant benefit
Greenhouse gas emissions	3	2	3	15	78
Local air quality	4	1	4	18	73
Operation, costs for road administration	20	33	16	16	15
Vehicle operating cost	3	17	16	31	33
Noise	2	3	16	31	48

Source: Ongoing PIARC stakeholders survey - "Electric Road Systems: A solution for the future?" project. Jacob and Caso Florez (2018)

eHighway: electrified heavy-duty road transport

A particular electric road system is the eHighway being developed by Siemens. Road applications of overhead catenaries to supply electricity to vehicles date back more than 130 years and are widely used by the rail sector. There are around 300 trolleybus systems in operation across the world, mostly in urban areas. Heavy dump trucks powered from overhead lines are a feature in several mines. This is a well-known technology in use for many years, although it has not been yet deployed extensively across highways.

The system has already been tested on public roads near the Port of Los Angeles on a one mile connection between terminals of the port and in Sweden on a 2 km stretch of highway that links a port to an industrial site. Several research projects are under-way in Germany and two 10 km field trials are under construction. The demonstration project in Sweden has performed above expectations and other electric road systems are also being tested. A longer pilot project will electrify 20 km to 30 km of highways. In 2017 The Swedish Transport Administration issued a National roadmap for electric road systems for the period of 2018 to 2022 (Pettersson et al., 2017). The next plan to be launched in 2022 may include electrification of the highways where most of the heavy goods traffic takes place. The backdrop to these decisions is Sweden's objective to achieve a 70% reduction of GHG emissions from domestic transport by 2030.

The study (Kasten, Mottschall, Köppel, and Degünther, 2016) commissioned by the German Ministry of Environment assessed various alternatives to decarbonise road freight in Germany. Electric roads with 77% had the highest well-to-wheel energy efficiency. Alternatives that convert electricity into chemical form like hydrogen or methane have much higher energy losses, with a well-to-wheel efficiency of 29% and 20% respectively. According to (Kühnel et al., 2018) with the current German electricity mix, hydrogen fuel cell vehicles produce more than twice as much GHG emissions as diesel trucks. Battery achieved 62%, which is closer to ERS. However, given the current state of technology there are several caveats in applying batteries to heavy-duty long-haul operations. The battery size required would cut available payload and would require infrastructure for super-charging which would be demanding on the grid during spikes in use throughout the day.

Furthermore, ERS can be associated with batteries. Besides supplying energy for direct propulsion it can be used simultaneously to charge batteries and use them outside the electric roads. This also means that not all elements of a major corridor need to be electrified, e.g. in tunnels, under bridges or other structures that pose a challenge to the installation of overhead catenaries. Since these vehicles are compatible with and complementary to other fuel technology under these stretches they can simply use the battery or other fuels (e.g. CNG/LNG, hydrogen, bio-fuel, diesel). In addition, most freight movement takes place in a limited part of the network. For instance, in Germany 60% of the heavy-duty vehicle emissions take place in 2% of the road network. The electrification of 4 000 km of highways as suggested by the German industry association BDI would cover 60% of all ton-km on the federal highways network – around 13 000 km in total. As a reference, in a 12-year period between 1956 and 1968 about 6 000 km of German railway lines were electrified. The costs of electrifying 2 000 km of network over a 10-year period is equivalent to 20% of current tool revenues for the same period (Kühnel et al., 2018).

Figure 34. eHighway demonstration in Sweden

Source: Akerman (Siemens) (2018).)

Any alternative fuel will require an important investment in the supply infrastructure (see Figure 17) – with the exception of drop-in power-to-liquid and biofuels which have other caveats (see the Alternative Fuels section). An overhead catenary system would in an initial phase have higher supply infrastructure costs per vehicle according to (Kühnel et al., 2018). For LNG the costs would be one-tenth of ERS. Hydrogen would be one-third (although in this case vehicle operating costs would be higher) and a network of high-performance charging stations for batteries would be close to two-thirds of the costs of an ERS of comparable scope. The work of (Kasten, Mottschall, Köppel, and Degünther, 2016) also took the energy production infrastructure and vehicle costs into account for different carbon neutral solutions. Their results show that electric roads had the lowest total costs – compared to ICE with very low emissions power-to liquids (PtL), LNG (power-to-gas) and Hydrogen. The recent study by (Cambridge Econometrics, 2018) argues that ERS would have lower operational costs than other options. It also states that the total infrastructure costs for batteries, hydrogen and ERS would be similar, but with ERS being less costly over time for an equivalent number of zero emission vehicles in service.

It is widely acknowledged that at least in its early phases the infrastructure costs of ERS could not fall solely on ERS users for it to provide a solid business case for fleet owners. The same can be said of other alternative fuels. This can already be seen from the public money flowing into electric charging stations, hydrogen re-fuelling stations and LNG stations. It should also be noted that all these estimations (for ERS and other options) are subjected to great levels of uncertainty since none of these solutions as actually been implemented at a large scale and part of the technology involved is far from mature – ERS or LNG arguably being more mature than Hydrogen or other Power-to-X solutions.

Discussion

Given the current available alternatives and foreseeable future, ERS seems like a viable option to decarbonise heavy and long-haul road freight. But this solution is only likely to be deployed at scale by 2030 in a restricted group of countries. The question then is if there can be technological innovations in the meanwhile that render these heavy infrastructure investments obsolete. It cannot be ruled out that in a 10-year timeframe batteries will be able to have energy densities that can be adopted for heavy trucks on long-haul operations.

Even if these batteries do exist they require setting up a network of fast charging stations which come at a high cost – even higher than ERS if these systems become mainstream according to some studies. Moreover, if this option is widely adopted the electric grid would have to cope with higher peak loads and be under additional stress. This leads to further infrastructure investment needs. On the plus side a battery-based system would allow for more decentralised and flexible deployment of the infrastructure and associated investments.

It should be noted that much of the discussion on the cost-benefit comparison of alternatives is based on assumptions of future developments associated with high degrees of uncertainty. This is certainly the case for hydrogen and batteries. Overhead catenaries are a tested technology that has been in-use for more than 100 years. It is widely employed by the rail industry, trolleybus systems and in some mines for heavy dump trucks, although it has never been applied in scale for road freight.

Part of this discussion is also very focused on the European-OECD context. Sweden - where planning and trials for ERS are comparatively advanced - has more demanding GHG emission reduction targets for road freight than the EU or the United States. In a number of developing countries the lack of available resources to finance these investments (and in other alternatives we might add), maintenance requirements and current state of the electric grid can affect the cost effectiveness of this solution. At the very least there will be longer timelines for deployment in those countries. Nonetheless, in regions with underdeveloped road networks, major upgrades and new construction can include from the start electrification which can provide savings in infrastructure costs installation and a pathway for implementation.

In the Swedish case it is estimated that with 400 trucks per day using the system (e.g. on a 100 km route) the system would achieve a break even compared to diesel and biofuels – taking into account environmental costs (Sundelin et al., 2018). ERS makes sense along high volume traffic corridors where a great part of tkm are realised. In a first stage these systems are likely to be associated with big generators of freight like ports and for shuttle type operations. They can then be applied to long-haul operations along highway corridors.

As for other zero emission alternatives there will be sizeable investment requirements associated with ERS. For this alternative to be attractive to fleet owners the financing of the infrastructure should not fall on the system users, at least at its early phases. The business models to construct and explore this alternative are not yet developed, but whatever the form a significant part of the funding will need to come from the governments. Private side agents that can be involved in the setup of this infrastructure (or for other alternative fuels) include the highways operators and utilities.

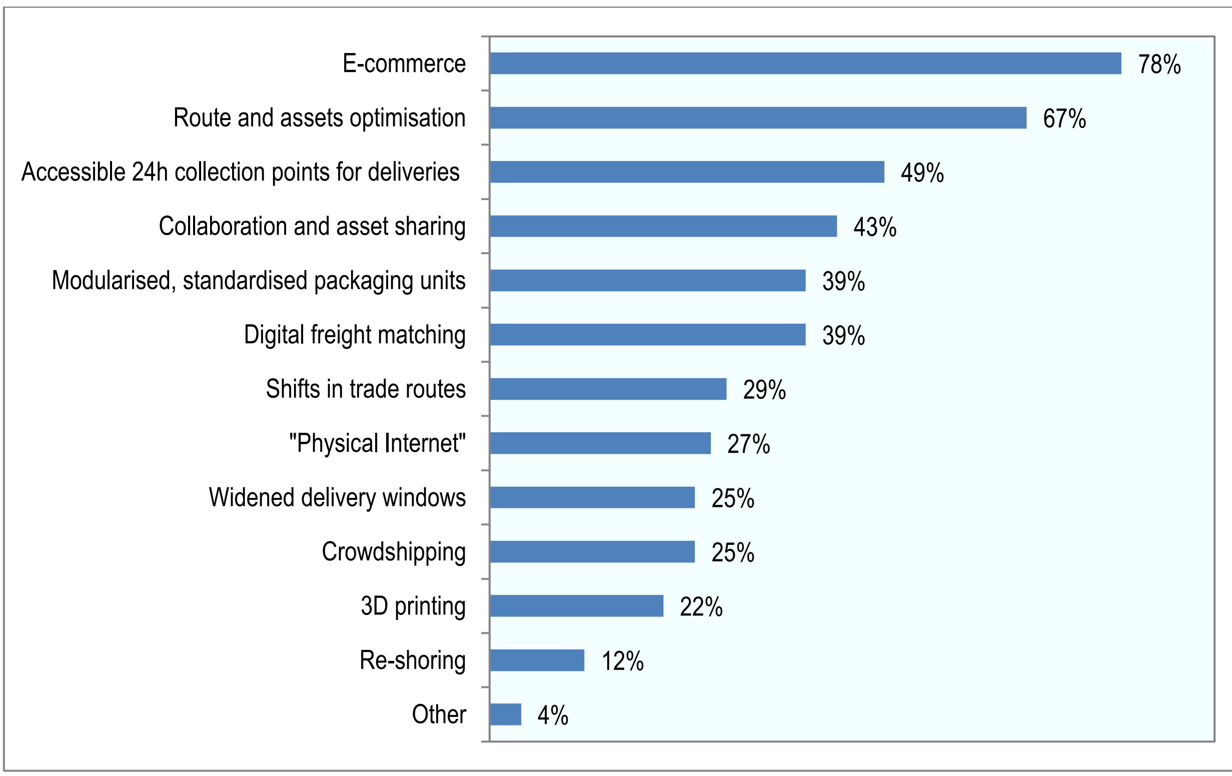
Key insights obtained in this section:

- Electric Road Systems (ERS) can play a role in the deep decarbonisation of heavy road freight. In the short-term additional trials and pilot projects are advised to further test the technology, business models and other operational aspects. This will also provide some time to assess developments in other fields and have a more informed comparative analysis before deploying ERS on a large scale, which in the most advanced cases will never happen before the mid-2020s.
- Time frames and the cost effectiveness of this system will necessarily differ in different countries and regions of the world depending on the attractiveness of other alternatives, state of the electric grid, highway system and other factors.
- Standardisation of equipment and processes is required, at least at a regional scale, in order to avoid inter-operability barriers (e.g. as is the case in rail) and take advantage of scale economies. Work in this area has already begun.
- In regions with underdeveloped road networks, major upgrades and new construction can include electrification from the start which can lead to savings in infrastructure installation costs and a pathway for implementation.
- Electric Road Systems (ERS) can be applied in heavy traffic corridors where most of the emissions are generated, but it will not fully replace all movements currently performed by internal combustion engine (ICE) diesel or gasoline engine vehicles. It will need to be complemented with other alternatives and has the flexibility to do so. This should take into account regional differences. In some areas electric batteries might be employed, in others Hydrogen or sustainable biofuels.

Emerging trends

This section addresses emerging trends shaping the sector. These are either new, untested phenomenon or exogenous changes imposed on the sector. Key examples are changes in trade patterns (e.g. impact of One Belt One Road), new commercial offers (E-commerce) and new forms of organising logistics (crowdshipping). The increasing relevance of non-OECD countries in global economic growth and transportation demand will also be discussed.

Figure 35. Likely trends and innovations to be present by 2030

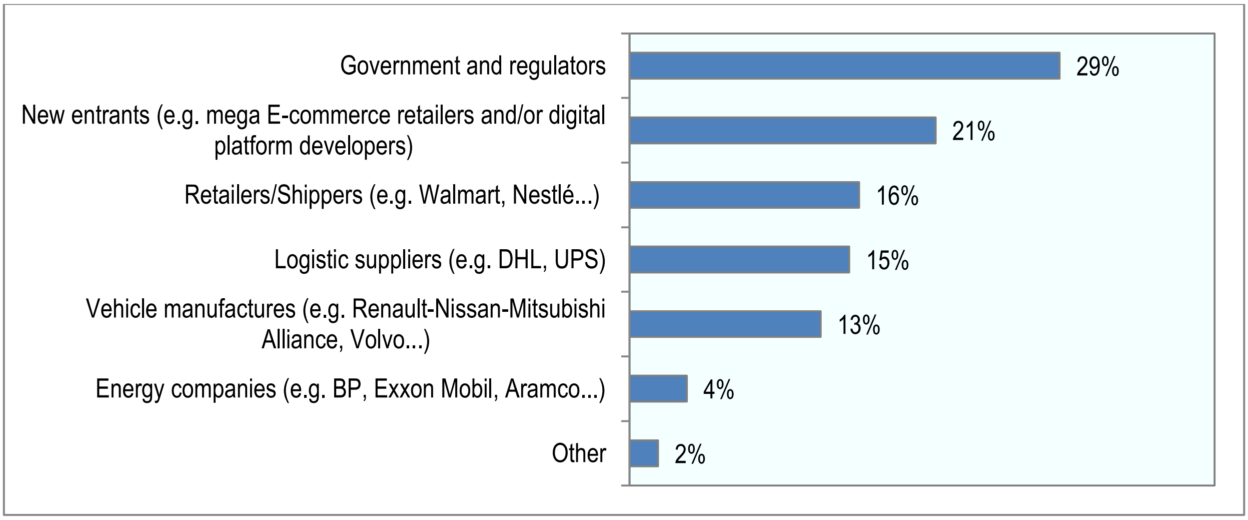


Source: ITF expert opinion survey (2018).

According to the ITF expert opinion survey Re-shoring was the least likely trend and 3D printing was second to last. These opinions could be based on the increased customisation of goods being done closer to consumer markets employing 3D printing in large scale. We are witnessing rising trade disputes and imposition of protectionist measures (OECD et al., 2018). If these persist they can change logistical global supply chains, shifting some of the nodes in that chain. This does not necessarily means re-shoring of production in a large scale. Production can simply move from one off-shore region or country to another.

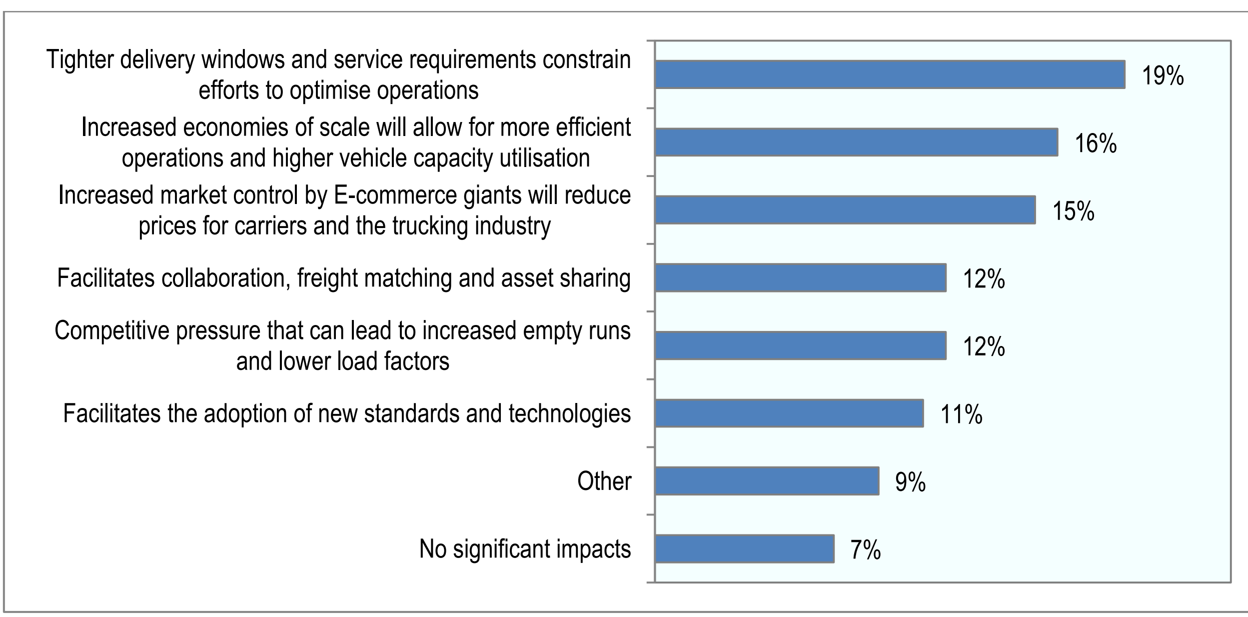
E-commerce was considered the most likely trend to be in place by 2030 in the ITF expert opinion survey. It was also considered the trend that would least contribute to reduce emissions (see Figure 27). Among four logistic related trends – e-commerce, crowdshipping, digital freight matching and collection points (see reader's guide for definitions) – the adoption of collection points was the option that could contribute more to reducing CO_2 emissions.

Figure 36. Agents who will lead transformations in the sector



Source: ITF expert opinion survey (2018).

Figure 37. E-commerce's most relevant impacts on the sector and efforts to decarbonise it



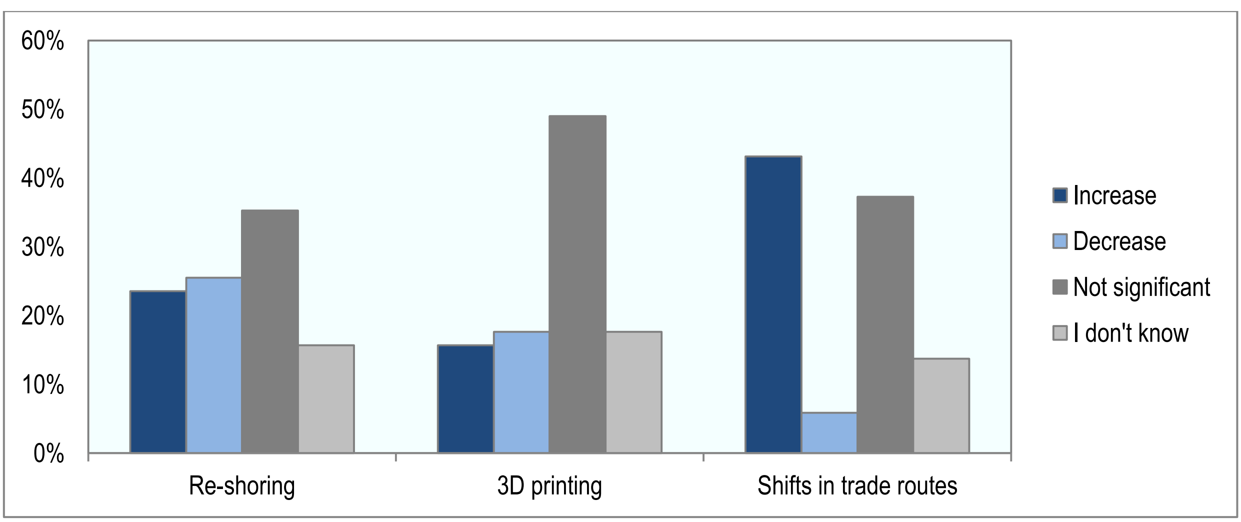
Source: ITF expert opinion survey (2018).

Opinion survey participants thought that new entrants from the private sector including e-commerce retailers and digital platforms will be the lead agents of change in the sector. This reinforces the growing importance of e-commerce and the need to closely monitor these developments and adapt policies to this emerging reality. One of the key impacts of e-commerce in relation to decarbonising is the ever tightening of delivery windows, constraining efforts to optimise operations and decreasing the use of available capacity. It can also push prices further down for carriers and increase competitive pressure that can lead to more empty runs and lower load factors. Greater ease of purchase and returns can also lead to increased demand and travel. Facilitation of more specialised demand can increase transport distances. The overall decrease in transaction costs might increase environmental impacts.

But there can also be upsides from this shift in the market. Increased economies of scale can allow for more efficient operations, facilitate collaboration and the adoption of new standards and technologies. It can also decouple the transport of goods and people, i.e. private individual trips for shopping trips could be replaced by delivery services. In the survey 61% of the respondents stated that e-commerce could significantly reduce private trips for shopping. Policy will play an important role on how e-commerce and other trends will impact emissions. Promoting the use of collection points, off-peak deliveries and zero emission vehicles in urban operations will contribute to emissions savings. Other policies – e.g. distance based charges - could be more focused on nudging business models to increase capacity use instead of practices that foster less efficient transport and more congestion. Underlying any policy actions is the need of more accurate data for evidence based decisions as previously discussed in the "Logistics and supply chain" section of the report.

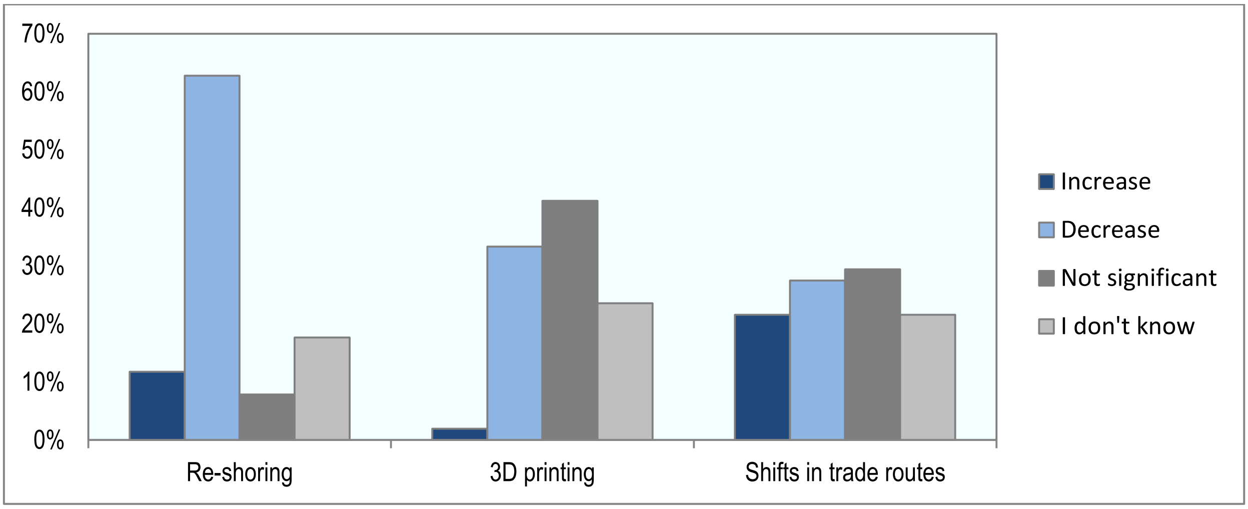
Possible trends like re-shoring or 3D printing are not seen as having a significant impact on demand. But shifts in trade routes could indeed lead to an increase. The impacts on transport distances are reversed. In this case the shift in trade routes will not be very significant. 3D printing and particularly re-shoring could have a significant impact in reducing distances. It should be highlighted that regardless of the survey answers, re-shoring would probably affect more the movement of goods between continents, hence air or sea modes more than road freight.

Figure 38. How will emerging trends impact road freight transport demand?



Source: ITF expert opinion survey (2018).

Figure 39. How will these trends impact road freight transport distances?



Source: ITF expert opinion survey (2018)

Presentation summaries

Emerging trends on demand and mode choice

Population and economic growth, plus a change in economic production in higher value-added goods in fast growing economies like the People's Republic of China and India has a number of implications on modal choice and fuel demand. Increases in per capita income are a driver of the shift towards higher value-added goods and overall increase in demand. This impacts transport by requiring higher speeds and accessibility. In China in particular road freight has taken over rail in tkm moved in the last 20- years. In India, road already had a higher share and it has attracted most of the growth in transport of goods.

The Belt and Road initiative (BRI) launched by China comes in the backdrop of these evolutions. An estimated 71 countries are involved in the project along the route. Parts of the manufacturing value chain are to be moved to participating countries. The Indian Ocean Rim Association (IORA) is an inter-governmental organisation which aims to strengthen regional cooperation and sustainable development within the Indian Ocean region. In contrast to BRI it does not aim specifically to create economic routes but it is a forum for dialogue on issues ranging from maritime safety to trade and investment facilitation.

A number of trends point to a reverse shift from rail to road, such as need of more economic flexibility or road and vehicle technology improvements. The setup of dedicated freight corridors, like envisioned in the BRI can however push for a shift towards rail. Co-modality and complementary between road and rail will be key to rationalising mode choice that delivers greater efficiency and sustainable answers to increasing demand in "fast growing economies".

Some open-ended questions include: to what extent can China's BRI create an environment for co-modality given the difference in regulations and legislation in countries along the routes? Another important topic is how the repositioning of Chinese and Indian firms will effect global and national movements of goods and will this continue the reverse modal shift to road?

Disruptive innovations for sustainable freight transport

Transport increase is being driven by economic growth, new business models like e-commerce and a trend towards more individualised small-scale deliveries. New technologies and managerial innovations will likely be needed to decrease global GHG emissions. The Friedrich-Alexander-Universität Erlangen-Nürnberg analysed their potential through a multi-rounded real-time Delphi method. Several experts were asked to assess different innovations on-line and were given real-time feedback and possibility to re-assess their judgement.

More than half of the experts came from academia with the remainder evenly split between industry, government or associations. There were participants from 25 countries, though more than three-quarters came from Europe (particularly Germany). The respondents were asked three questions: On the timing, if ever, of mass adoption (at least 30% market penetration); impact on sustainability and confidence in the assessment.

One of the key results of the survey is that vehicle utilisation is key to sustainable transportation. In this vision moving from digital freight matching to ever increasing logistical integration leading to the physical internet will play a major role in decreasing emissions. Another highlight is that the implementation of innovations in transport needs time due to long depreciation times of infrastructure and its high costs. Business model innovations such as the physical internet or 3D-printing might have a higher impact on sustainability than technological improvements (e.g. self-driving trucks or automated loading).

Figure 40. Surveyed innovations

1. **Battery electric trucks** (up to 40 tons) for deliveries up to 500 km (310 miles)
2. **Biofuel trucks** for long-haul deliveries (more than 500 km / 310 miles)
3. **Catenary technology** for heavy duty trucks (up to 40 tons) on highways
4. **Truck Platooning** on highways for long distances (more than 500 km / 310 miles)
5. **Self-driving trucks** for extra-urban traffic
6. **Pipeline supply networks** for long distance freight transport (more than 500 km / 310 miles)
7. **Drones** for last mile deliveries (up to 50 km / 32 miles) in urbanized areas
8. **Digital freight matching platforms** for last mile deliveries in urbanized areas
9. Freight is predominantly transported through a **shared open intermodal transport network** (Physical Internet)
10. **Internet of Things** to connect vehicle within a fleet and optimize freight transportation
11. Worldwide **modularized and standardized packaging** (from cargo container sizes to tiny sizes)
12. **Smart containers** elaborate the transportation route to their destination by themselves
13. Completely **automated loading and unloading** of transport vehicles through robotics or automated loading systems
14. Local **3D-printing** instead of transporting products

Source: Meyer (2018)

Expert surveys provide a snapshot view on the opinions of respondents that can provide a useful indication on the state of current thinking on logistics and sustainability. But the results will vary depending on the pool of participants engaged. As previously discussed in this report the prevailing consensus is that certain measures on vehicle technology can in fact produce immediate and effective results. These are also easier to measure and if applied at scale will directly influence fuel consumption and emissions. Managerial changes can play an important role, although much more uncertain given past experience and lack of available data. This uncertainty is even higher for untested measures estimated to occur in the mid to long term.

South Africa's road freight decarbonisation experiences

South Africa is a vast country with spatial challenges. It represents 0.4% of the world GDP but 1.4% of surface freight tonne-km. In Sub-Saharan Africa, South Africa represents 45% of the region's GDP but 80% of the CO_2 emissions. This trend has worsened in the last decades with the GDP share of the country in the region decreasing more than the share of emissions that remained rather stable. This is a vast country, particularly when compared to any European country.

The long distances, mix of commodities and spatial concentration of activities along certain corridors make rail and a shift from road to rail more promising than in Europe. The same can be said of India where rail's current position compared to road is less favourable than in South Africa.

The supply of transport in South Africa shows some inefficiencies. Given the country's geographical and economic structure the share of rail is lower than optimal. It decreased in the beginning of this century but since 2009 it has been slowly growing, but more is needed to increase the overall efficiency of the transport system. As a consequence of these inefficiencies logistic costs have been growing over time. There has been a massive increase in the truck fleet, greatly outpacing the growth in GDP and transportable GDP. This growth in vehicles has been particularly intense in HCVs that are already in use in South Africa, where the maximum permissible combination of axle loads available allows for 62 tonnes trucks.

Considering the above South Africa shows a will to decarbonise freight transport. After electricity generation road transportation is the main contributor for CO_2 emissions. Attitudes from logistic companies show some acceptance of this objective, surveys show that sustainability is important for almost all companies. Studies show that increased logistic and operational efficiency combined with modal shift could save almost half of the total road freight kms driven each year in South Africa. Several drivers can be mobilised to achieve this change.

On the policy side one of the instruments to be introduced to achieve decarbonisation is a carbon tax. A draft bill towards this end was produced in 2015 and implementation is likely in 2020. The tax will be at a rate of approximately USD 8-9 per tonne. But there are several caveats that can undermine its effectiveness. Businesses will initially have a 60% waiver. A complex system of discounts can reduce the effective tax rate to around USD 3 per tonne. On the infrastructure side there will be investments in rail to foster modal shift and also improvements to road quality. Also envisioned are the introduction of "productive neighbourhoods" that cluster different businesses and decrease the demand and distances for transport.

A critical problem affecting logistics efficiency in South Africa are missed slot times. Causes for this are delays at prior clients, traffic congestion or clients having full warehouses that prevent off-loading. Unnecessary trips or extra km made are caused by truck breakdown, incorrect deliveries or road obstruction (e.g. due to flooding). There are environmental or external factors that contribute significantly to these problems like crime, hi-jacking or strikes – as a reference in 2017 there were 1 180 hijacking incidents in South Africa.

On the culture and behaviour the voluntary Road Transport Management System (RTMS) programme has been very successful. It currently includes 250 fleets totalling 15 000 trucks and buses. In some examples it has contributed to a 24% improvement in fuel consumption and carbon emissions. It also leads to cost savings in fuel and repairs and maintenance. Cost savings are more important but the values saved in repairs are also significant, around 74% of the value saved on fuel. The increase in capacity use has often been mentioned in this report, but for some sectors in South Africa (e.g. forestry) overloading is actually a problem and this program started by addressing this practice. The main objective of RTMS has been to improve safety and it achieved very positive results. There have been less crashes, fines and vehicle breakdowns. This means less insurance costs, less unnecessary trips and vehicle-km, less disruptions and overall more efficient operations.

Discussion

Most of the increase in demand for freight transportation will occur outside OECD countries, South Africa is such an example. There are corridors where currently 2 000 trucks circulate every day, in a period of 30 years this number is forecasted to increase to 8 500 trucks without modal shift. Even by achieving an optimal modal share distribution that takes into account the type of commodities moved and the density of flows, the number of trucks in circulation will still double. This will have consequences in emissions, but also put a strain on the infrastructure, increase congestions and disruptions to transport. These will be multiplied if there is no modal shift where conditions allow it.

India is a country where there is also potential to move freight from road to rail, but one of the critical issues is the function played by railroads in society. Rail is considered a social good and a way to provide low cost mobility for the population. The rail network is passenger oriented and freight returns are employed to subsidise passenger services. Besides infrastructure investments, changes in policy are required to achieve modal shift. In countries such as India and South Africa with long distances and demand concentrated along certain corridors modal shift has a greater potential than other regions such as Europe.

Large trans-continental projects such as the Belt and Road Initiative can impact the transport of goods. But given the nature of these initiatives modes involved in very long distance trips will likely be more affected than road, e.g. shipping, air or rail. At least when trans-continental flows are considered, regional connections between countries along these routes can impact road freight and increase the volume of activity.

Transport and logistics are undergoing transformations and these will likely be even more disruptive in the future. Technology, business models and the road haulier’s market structure can suffer major changes. The changes in technology will affect different actors in very different ways. Those that take advantage of these changes will gain the most while other might see their roles diminished or even disappear. For instance, having fully autonomous trucks can cut costs by around 30%. If they are widely applied (e.g. many highway corridors connecting distribution centres or other important generators of demand) companies that do not participate will not be able to survive. This can affect many small operators and concentrate the market. For policy to monitor and – as much as possible – keep up with these developments and their effects having accurate data and analysing it is critical.

Key insights obtained in this section:

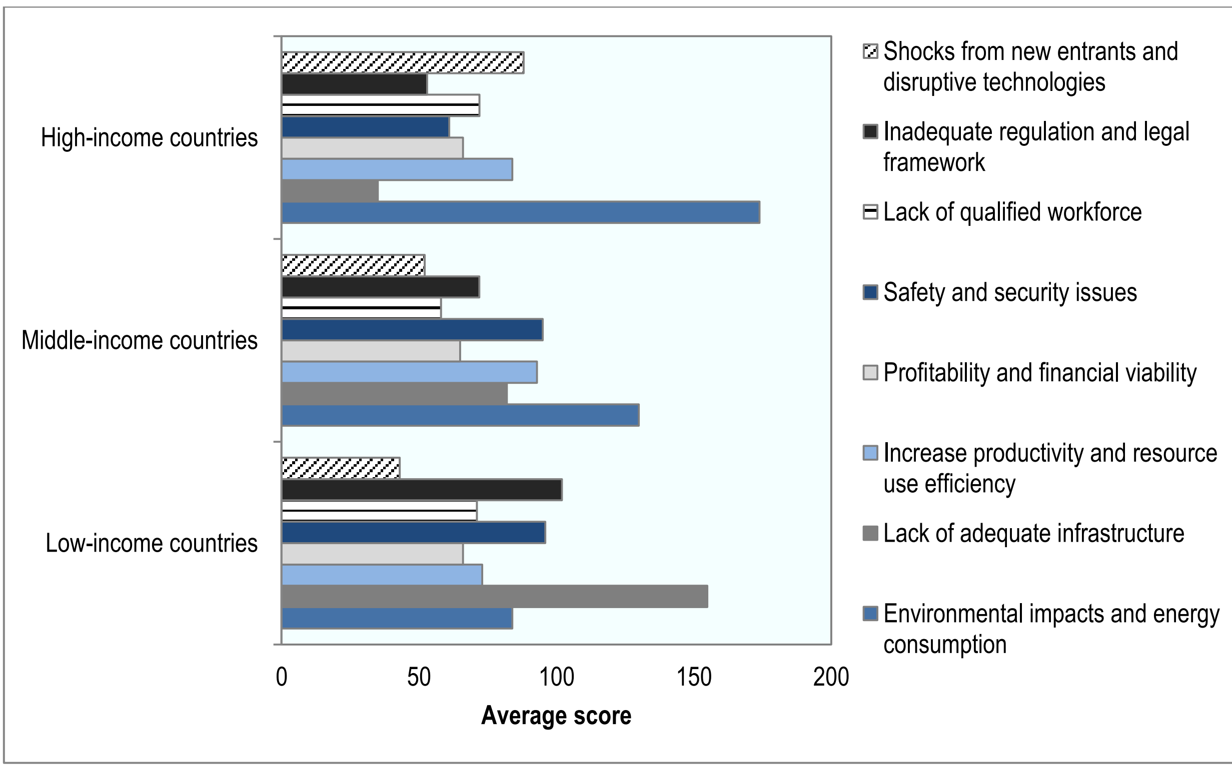
- Modal shift can play a role in decarbonisation in countries such has South Africa or India, more than in Europe.
- Taking a global perspective there are several “low hanging fruit” measures that can be of great effect in the countries outside the OECD where most demand is going to take place (e.g. renewal of existing truck fleets and improving diesel fuel quality).

- Access to accurate data, including new sources is required for sound policy decisions. This is particularly critical to monitor and estimate the impacts of disruptive changes affecting logistics (e.g. impact of autonomous trucks or growing influence of e-Commerce).
- E-commerce is already changing logistics and is likely to play an increasingly dominant role. This can brings some opportunities to decarbonise (e.g. gains with scale economies), but if unchecked is more likely to lead to increased emissions and congestion. Policy can play a role in shaping these developments (e.g. fostering the use of collection points and zero emission vehicles for deliveries, which can include zoning restrictions for emission intensive vehicles in urban areas).

Review of policy implications

In this section we will address some of the policy tools and challenges involved in road freight decarbonisation. We will start by looking at pressing challenges and policy priorities identified in the survey for different types of countries.

Figure 41. Pressing challenges for policy makers



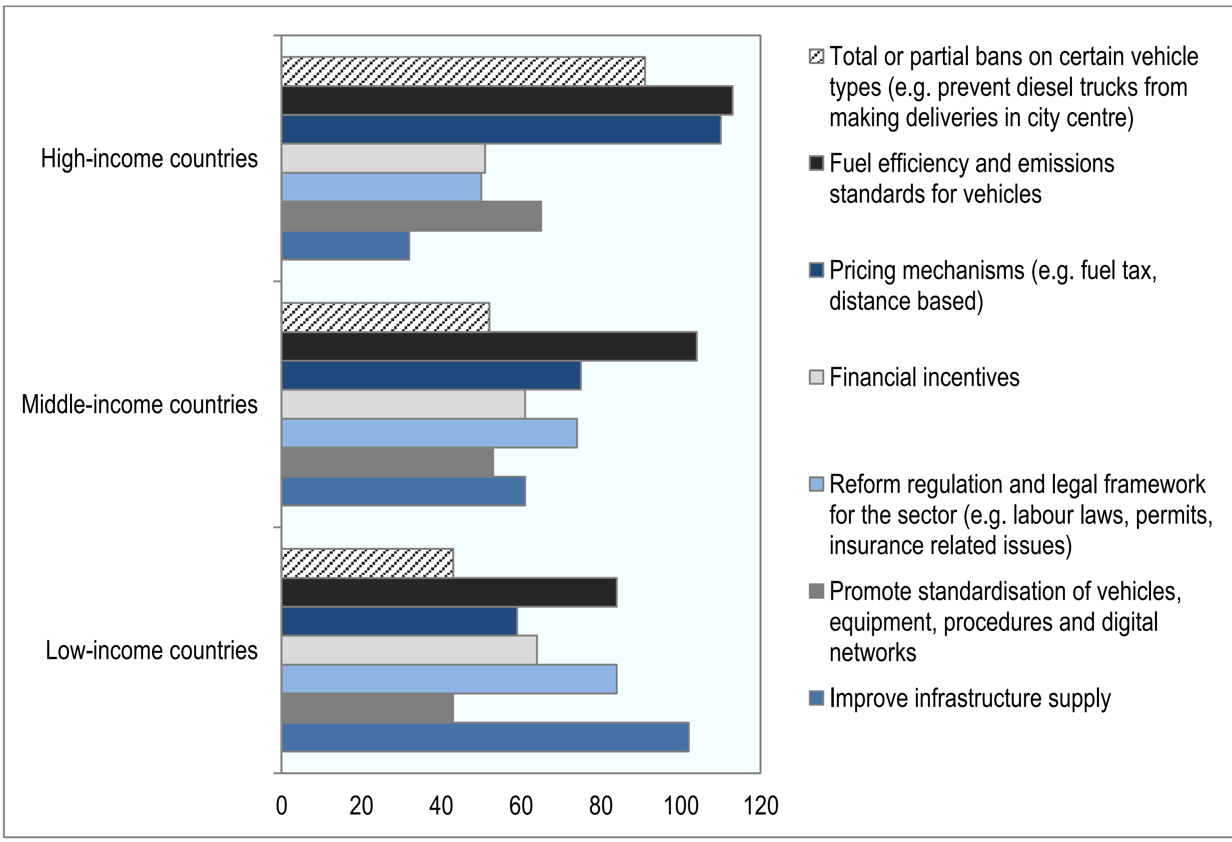
Source: ITF expert opinion survey (2018).

Opinion survey participants identified environmental impacts and energy consumption as the main pressing challenges that policy makers should be aware of for both high- and middle-income countries (see country type definitions in the reader's guide). Increased productivity and resource use efficiency ranks third in the list of concerns for these countries. In the high-income group the second main challenge are shocks from new entrants and disruptive technologies. This highlights the moment of transformation the sector is going through with new business models and technologies shaping the sector, something that has been discussed in several of the previous sections of this report.

Safety and security is the number two pressing issue for middle-income countries, which underlines some of the points made in the presentation about the situation in South Africa and that could be applied to other countries in this group, e.g. Brazil. Low-income countries the lack of adequate infrastructure were identified as the most critical problem, followed by inadequate regulation and legal framework. Safety and security ranked third, and is as so pressing as for middle-income countries but also ranking high in the list of challenges.

Resilience was another issue identified in the survey. Uncertainty from exogenous events is rising - e.g. climate change or disruptions to trade – which puts a renewed emphasis on the need for system resilience. The pursuit of ever greater efficiency can degrade resilience - these two needs should be balanced.

Figure 42. Policy priorities



Source: ITF expert opinion survey (2018).

Fuel efficiency and emission standards are a key policy priority in all country groups. Particularly for the high- and middle-income where it is the number one priority, but even for low-income countries it ranks in the top three policies. Pricing mechanisms are number two on the list for the high and middle groups, this can include a carbon tax, distance-based charges or other toll systems that promote cleaner technology vehicles and greater efficiency. Total or partial bans of certain vehicles (e.g. ban diesel vehicles from making deliveries in the city centre) is the third on the list of priorities for high-income countries, reflecting the drive and future policy commitments that are taking place in several cities and countries around the world (mostly in OECD countries).

Regulation reform is the third priority for middle income countries, ranking higher than bans or infrastructure supply improvements. It is even a higher priority for low-income countries. Although for the latter, improving the infrastructure supply is considered the most important policy. Having listed the main priorities for each country group it should be noted that a policy package that pushes road freight towards decarbonisation should include all of these elements. Infrastructure supply receives the least priority on high-income countries, but even there large investments will be unavoidable when deploying zero emissions fuel technologies. Nonetheless, the differences shown in the survey underline an insight previously addressed in the report: the pathways for decarbonising should to be adjusted to the realities in different regions of the world.

Presentation summaries

UN vehicle regulations agreements and activities related to heavy-duty vehicle fuel economy

The World Forum for Harmonization of Vehicle Regulations (WP.29) is the unique worldwide regulatory forum for the automotive sector; it administers three Multilateral UN Agreements (1958; 1998; 1997) that cover issues such as emissions of pollutants and CO_2, noise, general safety or lighting and light signalling among other topics. The UNECE Sustainable Transport Division has been the Secretariat to WP.29 for more than 60 years. These agreements are open to all Nations of the UN, states, governmental organisations and NGOs but decisions are taken by the governments of the contracting parties (CPs) – countries that joined the agreements.

The 1958 agreement provides a legal framework for the adoption of uniform UN regulations on vehicle manufacturing. It provides reciprocal recognition of Type Approval for vehicle parts and systems approved according to UN regulations on the 1958 agreement. Once a vehicle part is approved following these regulations, it is accepted under these regulations by all contracting parties to the agreement. The agreement is an instrument to eliminate trade barriers. More than 140 regulations are annexed to this agreement covering all kinds of products and parts. The agreement has evolved having gone through several revisions. The parts and systems approved receive a unique marking - E on a circle with the version number; currently on version 6 - an approval number and the approval date with test reports.

The 1998 agreement does not have administrative provisions for certification and homologation. It provides the legal framework for adopting uniform Global Technical Regulations (UN GTRs) whereby the CPs commit to implementing these GTRs into national legislation when they join the agreement. The 1997 agreement concerns reciprocal recognition of vehicle technical inspections.

Heavy-duty fuel efficiency standards have been adopted or are soon to be adopted in all major markets. But the methodologies to measure fuel efficiency and CO_2 emissions up until now have been specific to each country or region. The need to harmonise these measurements has been mentioned before in this report and countries and the industry recognise its importance. The UNECE Sustainable Transport Division is developing efforts towards a harmonisation framework. A first critical step is setting the methodologies for measuring the parameters used as inputs in the simulators that calculate the emissions and fuel consumption (e.g. method and equipment to measure air drag, tyre rolling resistance or engine parameters). The simulation tools (e.g. EU/VECTO, US/GEM) employ similar analytical methodologies and provide comparable results for the same inputs. Another aspect to take into account is the vehicle classification, which is also distinct for different regions in the world. This should be as simple as possible, but still take into account real world complexities.

It is very challenging to reach multilateral international regulations and accommodate all the different standards and interests at stake. However, they provide a host of advantages. On the vehicle manufacturer side they facilitate international trade, decrease the technical barriers for export/import, reduce the uncertainty of market acceptance and provide harmonised requirements across different markets. For users they mean facilitated border crossings and interoperability, additional safety guarantees and easier access to state of the art technology. This is very relevant for the widespread adoption of fuel efficiency technologies. The harmonisation of emission measurements would also allow greater transparency, comparability and improved estimates of current and future CO_2 emissions.

Korea's greenhouse gas mitigation policies in logistics

The Korean government established the Sustainable Transportation Logistics Development Act in 2009 and set up a Master Plan for Sustainable Transport Logistics Development in 2011. The Master Plan includes measures to promote modal shift, the development of third-party logistics (3PL) and common logistics, plus green technology. For 2020 the transportation sector greenhouse gas (GHG) reduction target is 34.3% compared to the estimated baseline emissions for that year. It is more ambitious than the overall country objective of 30% reduction by 2020. The national reduction from the baseline scenario for 2030 is 37%. To provide some context transportation was close to 15% of total GHG in 2014 for Korea, whereas globally transport emissions accounted for 22% of the total.

One of the key goals of the Korean Master Plan is to incentivise 3PL and common logistics across companies. The goal is increase assets utilisation, including vehicle capacity utilisation and to decrease empty runs. A feature of the Korean economy is its very large companies who have their own logistical arms. They tend to use their in-house services which reduce the opportunities to optimise overall logistics, as previously discussed in the Logistics section of this report. The 3PL market is reduced and dominated by small-sized companies.

Several initiatives are envisaged to foster modal shift from road towards rail and coastal shipping. This includes a subsidy to cargo that moves to heavier modes that can go up to 30% of the social environmental costs saved with this shift. Other measures include improvement of port and rail networks and their connections, recruiting of crews for coastal shipping and establishing an integrated shipping network.

On the vehicle technology side there are a range of options being explored. Some noticeable examples are the support for LNG and diesel hybrid trucks, vehicle weight reduction programmes, adoption of equipment to improve aerodynamics (e.g. side skirt and boat tail), the introduction of HCVs on certain corridors or in-vehicle monitors of fuel consumption and driving behaviour. For temperature-controlled transportation delivery vehicles equipped with Phase Change Material (PCM) technology will be introduced. PCM materials store and release thermal energy during phase transition (solid to liquid or vice-versa). They can provide active cooling during transport significantly reducing vehicle fuel consumption that would otherwise be needed to operate traditional coolers/freezers.

The plan also aims to incentivise voluntary target reduction programmes similar to "lean and green logistics" described in the section Logistics and supply chain. The program includes assistance for measure and analysis of energy use of the companies involved, set up and revision of implementation plans, providing access to know-how and facilitation of exchange of knowledge.

Looking at the mitigation policies for 2030 a crucial aspect to tackle is the lack of accurate data. An important objective is to enhance MRV (Measurement, Reporting and Verification) systems to calculate emissions both at the national and companies level. Having tested methodologies to estimate emissions savings is necessary to evaluate the effectiveness of the technical and logistic measures that are part of the Master Plan. This will greatly assist in the further development of current initiatives and new policies. Having accurate accounting of emissions per company is also necessary to the introduction of an emissions trading scheme. Other related tasks are the establishment of a GHG emissions database management system to analyse emissions by company and link emission savings to costs.

Discussion

Multilateral international technical regulations offer a platform for harmonisation of standards, methodologies, equipment interoperability and acceptability across borders. Measuring emissions, assessing the impact of different policies or having mainstream adoption of more fuel efficient technologies are all areas that could benefit from international harmonisation and standardisation.

Policy making has to consider multiple and sometimes contradictory interests and objectives. What benefits one economic sector might adversely impact others, the weight and power these sectors have in a country will shape decision making. These differences and contradictions in the economy and society can also be reflected inside the governments with each ministry defending their area of responsibility. Although these disparities are to a certain extent unavoidable, policy design for road freight decarbonisation include coordination from all relevant ministries, government agencies and businesses. There should be an effort to align policy objectives with all legitimate interests expressed within the government, society and businesses – particularly those that are more directly involved with the actual implementation of measures and practices that will lead towards decarbonisation.

Key insights obtained in this section:

- Set a pathway for decarbonisation with measures and policies that governments can implement now. This should involve low-technology solutions or already tested and matured technologies. But steps also need to start on options that involve larger investments, higher political and business risk and more advanced/experimental technologies and business models. Achieving climate change targets will also require the latter, their timing and exact configuration will and should vary by world region.
- Define regional best practices and a set of policy packages adjusted to each region.
- Promote cross-border harmonisation of methodologies and equipment interoperability for the widespread adoption of best practices and technologies.
- Policy design should involve and align the objectives of all relevant government bodies, businesses and civil society. Given that there are contradictory interests even between government agencies leadership and strong political will are required to set up coherent policy packages that encompass all relevant sectors for implementing road freight decarbonisation.
- The importance of data and methodologies to assess the impacts of different policies was again underlined.

Conclusions

Decarbonising road freight has to move higher in the overall decarbonising policy agenda. Road freight transport is estimated to be the number one sector in energy consumption and emissions increase. Worldwide the sector consumes around 50% of all diesel produced and it is responsible for 80% of global net increase in diesel use since 2000 (IEA, 2017). Furthermore, road freight activity is predicted to more than double from 2015 to 2050. This increase in demand will offset expected gains in efficiency and lead to an increase in emissions by 2050 (ITF, 2017a). According to baseline projections trucks are the fastest growing source of global oil demand accounting for 40% of the oil demand growth to 2050 and 15% of the increase in global CO_2 emissions. Indeed, trucks will even surpass passenger cars as the major oil consumer sector. These figures show not only road freight's current sizeable contribution towards CO2 emissions, but its increasing relevance towards the overall decarbonisation effort. As other sectors slow their emissions growth and even decrease them, this has not happened to the same extent in the transport sector, particularly for road freight.

A roadmap towards decarbonising involves implementing measures now with low barriers to adoption that have already been tested and have clearly been identified as a requirement to cut emissions. Technologies that improve the fuel efficiency of diesel heavy vehicles are a fundamental component of a pathway towards decarbonising road freight (e.g. aerodynamic, reduced-rolling resistance of tyres, weight reduction, increased engine efficiency and hybridisation). In the short- to medium-term this is where a significant part of emissions savings can be delivered, particularly for heavy trucks on long-haul operations. Fuel economy and CO_2 emission standards and regulations are necessary to foster the widespread deployment of these solutions, it is critical that they also include heavy freight trucks.

Eco-driving is one of the most cost-effective measures to save CO_2 emissions. It is a paradigmatic example of a "low hanging fruit". Several large companies already have adopted this practice, but there is still room to expand its application, namely for mid-and small-sized companies. Eco-driving can and should be coupled with on-board systems that monitor fuel consumption and provide feedback to the driver. In fact, regular monitoring and feedback on driving behaviour is critical for the lasting success of this measure. Route and assets optimisation along with an array of ITS options are also low barrier initiatives that can contribute towards decarbonising the sector.

For urban type operations alternative fuels are already a viable commercial solution or will be in the short-term. For instance, under some circumstances there is already a business case for electric battery light commercial vehicles (LCVs) in cities. In the near future they will be more cost effective than traditional internal combustion engine (ICE) diesel/gasoline engines. Policy should foster the adoption of alternative fuels in cities - e.g. pricing mechanisms and incentives, stricter emission standards, zero emission zones, promoting common standards for equipment, supporting recharging infrastructure or adopting alternative fuels for public institutions vehicle fleets or other large fleets.

Relaxing restrictions on truck length and weight and allowing high-capacity vehicles (HCVs) is a tried and tested cost effective solution to decarbonise road freight. These vehicles are already in operation in a number of countries (with some restrictions on the routes they can be employ, e.g. in Finland they cannot use certain designated bridges). HCVs can operate on specific corridors where there are no infrastructure barriers or more energy efficient heavy modes alternatives. Their safety and efficiency standards should be more stringent than for regular size heavy trucks, as it is already the case in some countries in which they operate.

Development and adoption of common standards for new equipment and processes (e.g. electric batteries chargers, electric road systems (ERS) or modular packaging units) is necessary to facilitate widespread adoption. Harmonisation of methodologies to measure emissions is required to properly identify best practices, assess policies and the contribution of different technology packages to decarbonisation.

Recognition among peers and the wider public is an incentive for businesses that want to lead efforts to decarbonise. Voluntary schemes where companies and other partners cooperate to achieve targets and implement pathways toward greater sustainability also play a role. Governments and other public entities can help kick start these initiatives.

In many developing countries renewing truck fleets – that are old and mostly made up of second-hand vehicles not in their prime performance – would be one of the most important immediate tasks. This is associated with improvements to diesel fuel quality and reduction of “black carbon” emissions. Increasing driver training and maintenance levels would also contribute to save emissions, increase safety and reduce costs.

The current importance of data for logistics and decarbonising cannot be over-estimated. Data plays a critical role in policy making. The data required to properly estimate critical indicators like vehicle capacity utilisation currently exists (at least in a number of countries), but it is mostly property of private companies. Access to private data from public entities is a critical issue. This data is required for better informed policies. Part of the data has sensitive commercial information and there are privacy concerns. These should be properly taken into account when accessing, analysing and sharing information obtained from the analysis. Besides the data itself, new modelling tools and more disaggregated approaches would help to obtain more meaningful insights for policy makers – and the industry. The relevance of data extends to the proper evaluation of disruptive business models and potential impacts of new vehicle technologies.

Collaboration across companies has the potential to leverage great savings in costs and emissions. Up to now inter-company collaboration has only been implemented at a localised experimental level. Scaling up these experiments is critical to unlock the potential of logistic measures in decarbonising. Policy and regulation should not be a barrier to logistical collaboration. Antitrust laws can hinder efforts for horizontal collaboration in logistics and have already prevented some experiments. An important challenge to the industry, but also for policy makers, is to deploy new digital technologies to enhance cross company collaboration and increase logistics efficiency while complying with antitrust laws. Digital platforms operated by neutrally trusted third parties offer a promising pathway to overcome these barriers and unlock the potential of collaboration which taken to its maximum potential can lead to the “physical internet”.

Long-haul heavy trucks generate most of road freight’s energy needs and emissions. Deep decarbonisation will require the employment of zero emission alternative fuels. It is increasingly hard to find cost-effective alternatives as the vehicle sizes and ranges increase. Given the current state of research and commercial deployment no zero emissions solution in widespread use is foreseeable in the short- to medium-term for long-haul heavy freight trucks. Nonetheless, these alternatives need to be in general use by 2050 or earlier if climate change targets are to be reached. Direct supply of electric energy to the vehicle (electric road systems ERS), hydrogen and possibly electric batteries are currently foreseeable technologies that can assure zero emissions for heavy-duty long-haul trucks. Hydrogen has the drawback of having very low energy efficiency when produced from electricity or requiring CCS when generated from steam-methane reforming. Like with other alternatives the production, distribution and refuelling infrastructure has high costs. These can be even higher for ERS, although this would be the most energy efficient solution which also delivers the greatest emission savings. These options can be complementary up to a point, e.g. with ERS being used to charge batteries.

It is highly unlikely that one single option will be able to replace ICE diesel or gasoline engines. Even if electric roads are a very efficient way to power long-haul heavy operations this solution will not be able to cover all trips. Hydrogen, electric batteries or advanced biofuels could be used as a complement to electric roads on the regions or trip legs that are not covered by the electric road infrastructure. Strategic policy choices will likely have to be made regarding the set of options to scale up. To reach the mainstream solutions need to be available at national or regional level. The fact that some alternatives can be complementary does not mean they should totally overlap. This is particularly true of the significant investments and recourses that will need to be mobilised to deploy the alternative fuel infrastructure – production, distribution and recharging/refuelling. Although scaling up solutions implies prioritising, at this stage some flexibility should be considered. There is still some uncertainty associated with the feasibility of widespread adoption of alternative fuels, particularly for long-haul heavy trucks. Many of these technologies and processes are at early stages of development and deployment. Even technologies that have been in use for decades (like overhead catenaries) have not been deployed in scale for this purpose. To some extent, trial and error should be allowed and encouraged. Even if not foreseeable now, breakthroughs in advanced biofuels or carbon capture and sequestration (CCS) cannot be ruled out.

It is also important to recognise that the logistics sector - and transport at large - is undergoing substantive changes. E-commerce has been steadily growing and it is predicted to further increase. This has already affected the logistics sector and more changes are likely to happen. New entrants including digital platform providers will be the leading agents of change in the sector. At the same time boundaries and roles are shifting, with retailers becoming logistic suppliers and logistic suppliers entering retail. Other disruptions will come from increased vehicle automation. The ability to decrease or totally remove labour costs, plus a more flexible use of the vehicles can significantly cut costs and change the road transport market.

New business models offering free returns and requiring ever tighter delivery windows, constrain efforts to optimise operations and decrease the use of available capacity. Lower transport and transaction costs can lead to a growth in demand. Promoting the use of collection points, off-peak deliveries and zero emission zoning will contribute to save emissions. Other policies –e.g. distance based charges - could nudge distribution to increase vehicle capacity use instead of practices that foster less efficient transport and more congestion. Increasing vehicle automation and driver assistance is a reality, even if full automation is a longer-term perspective limited to certain markets. The truck driver tasks are shifting. It will increasingly play a managing and monitoring role, while decreasing direct control requirements. Driver regulation needs to be updated as the role behind the wheels decreases and the tasks behind the screens increase. Higher returns for companies can be reinvested in increased efficiency and alternative fuel technologies made necessary by stricter emission standards.

A fundamental fact encompassing this discussion is that freight is a commercial business operated by private companies. This is a critical difference from the passenger transport side where public bodies and authorities are much more involved (including in the direct provision of services) and trip choices are associated with personal behaviour. For road freight industry agents are the ones that ultimately define their operational procedures and supply chains so they need to play a leading role in decarbonising the sector. Companies have a direct self-interest in improving their operational performance and to cut costs. In order to change behaviours in the industry and adopt new logistical practices it is necessary to leverage the business case of new proposals alongside with wider societal benefits.

From a company's perspective it might make perfect sense to take on extra costs if this can be compensated by increased revenue. Furthermore, even in logistics transportation is not the only cost companies have to contend with (e.g. inventory or warehousing). Savings gained with lower transport costs can be re-invested in other domains. Measures that can reduce costs for some company types might not be so attractive to other players (e.g. suppliers and receivers in off-peak deliveries). Policies and initiatives that align the interests of all agents involved will be easier to implement.

Alternative fuels and fuel efficiency improvements need to be attractive for fleet owners. High initial costs and risk aversion dissuade companies from these investments even when the total ownership costs (TOCs) are lower and payback periods are short. Addressing this question involves tackling other barriers such as: lack of strict fuel and emission standards, the lack of incentives and understanding that small companies with limited resources play a very important role in this market. Zero emission technologies, particularly for the long-haul, will require substantial investments in the supply infrastructure whatever alternative is scaled up. The business models to construct and explore this infrastructure are not yet developed, but whatever the form a significant part of the funding will likely need to come from governments.

There is great uncertainty surrounding the extent to which re-shoring and 3D printing will increase in relevance. According to the ITF survey these were some of the least likely trends to take place, but other sources point to a greater uptake of 3D printing. Since the 2008 crisis there was a decrease in the elasticity of global trade to GDP. This has happened at the same time there are rising trade disputes and protectionist measures. If these persist they can change logistical global supply chains, shifting some of the nodes in that chain. This does not necessarily mean re-shoring of production in a large scale. Large trans-continental projects such as the Belt and Road Initiative can impact the transport of goods. Modes involved in long distance trips will likely be more affected than road, e.g. shipping, air or rail. Behavioural changes might also play a role. In developed countries, particularly after the 2008 crisis, there is a trend to value and spend more on experiences (e.g. travelling, eating out), than on material goods (e.g. furniture or clothes).

Road freight decarbonisation requires implementing now the measures with low barriers that have some effectiveness in reducing emissions – these are low tech solutions and those with mature technology. Achieving climate change targets will also call for the medium- to long-term widespread adoption of solutions not yet fully developed, be it in logistics or technology. Policy needs to evolve in order to create a favourable environment for the deployment of these solutions and adjust to emerging trends that can further disrupt freight transport. Improved and extended data collection is critical to design and re-asses these policies. The timing and exact configuration of road freight decarbonisation pathways should be adjusted to the different geographies and economies of each region of the world.

References

AEA and RICARDO, (2011), *Reduction and Testing of Greenhouse Gas (GHG) Emissions from Heavy Duty Vehicles-Lot 1: Strategy*,. Retrieved from https://ec.europa.eu/clima/sites/clima/files/transport/vehicles/docs/ec_hdv_ghg_strategy_en.pdf

Akerman, P., (2018), "eHighway: Electrified Heavy Duty Road Transport". Retrieved August 3, 2018, from https://www.itf-oecd.org/ehighway-electrified-heavy-duty-road-transport

Alvarez, R. A., D. Zavala-Araiza, D. R. Lyon, D. T. Allen, Z. R. Barkley, A. R. Brandt, S. P. Hamburg, (2018), "Assessment of methane emissions from the U.S. oil and gas supply chain.", *Science (New York, N.Y.)*, Vol. 361/6398, pp. 186–188. https://doi.org/10.1126/science.aar7204

Bloomberg News, (2018), "Can Electric Cars Make China This Century's Detroit?". Retrieved November 9, 2018, from https://www.bloomberg.com/news/articles/2018-08-24/can-electric-cars-make-china-this-century-s-detroit-quicktake

Bossel, U., (2006), "Does a Hydrogen Economy Make Sense?", *Proceedings of the IEEE*, Vol. 94/10, pp. 1826–1837. https://doi.org/10.1109/JPROC.2006.883715

BYD, (2018), "BYD Battery Electric Truck" BYD. Retrieved from http://en.byd.com/usa/wp-content/uploads/2017/06/t9-final.pdf

Cambridge Econometrics, (2018), *Trucking into a Greener Future*,. Retrieved from https://europeanclimate.org/wp-content/uploads/2018/08/Trucking-into-a-Greener-Future_Final.pdf

Cazzolla Gatti, R., J. Liang, A. Velichevskaya, and M. Zhou, (2019), "Sustainable palm oil may not be so sustainable", *Science of The Total Environment*, Vol. 652, pp. 48–51. https://doi.org/10.1016/J.SCITOTENV.2018.10.222

Cebon, D., (2018), "Blog: Should lorries be powered by Hydrogen? - The Centre For Sustainable Road Freight". Retrieved August 17, 2018, from http://www.csrf.ac.uk/2018/06/should-lorries-be-powered-by-hydrogen/

CO3, (2018), "CO3 Collaboration Concepts for Co-modality". Retrieved August 31, 2018, from http://www.co3-project.eu/

Crozet, Y. and A. Woodburn, (2014), *Development of rail freight in Europe: what regulation can and cannot do*, Brussels. Retrieved from www.cerre.eu

Daimler, (2016), "Daimler's advances in fuel efficiency and zero emission activities". Retrieved from https://www.iea.org/media/workshops/2016/thefutureroleoftrucks/5_Schuckert_Daimler_IEA.pdf

Delgado, O., F. Rodríguez, R. Muncrief, B. | Berlin, | Brussels, | San, M. Boenning, (2017), *Fuel efficiency Technology in european heavy-DuTy vehicles: Baseline anD poTenTial For The 2020-2030 Time Frame*,. Retrieved from www.theicct.org

Dimitropoulosi, A., W. Oueslatii, and C. Sintek, (2016), *The Rebound Effect in Road Transport: A Meta-analysis of Empirical Studies*, (OECD Environment Working Papers No. 113). https://doi.org/https://doi.org/10.1787/8516ab3a-en.

Dutch Ministry of Infrastructure and the Environment, CEDR, and RDW, (2016), *European Truck Platooning Challenge 2016 Lessons Learnt*,. Retrieved from https://eutruckplatooning.com/PageByID.aspx?sectionID=131542&contentPageID=529927

Earl, T., L. Mathieu, S. Cornelis, S. Kenny, C. C. Ambel, and J. Nix, (2018), *Analysis of long haul battery electric trucks in EU - Marketplace and technology, economic, environmental, and policy perspectives.*, Brussels. Retrieved from https://ec.europa.eu/inea/en/ten-t/ten-t-projects

EEA, (2010), "Load factors for freight transport — European Environment Agency". Retrieved October 12, 2018, from https://www.eea.europa.eu/data-and-maps/indicators/load-factors-for-freight-transport/load-factors-for-freight-transport-1

European Comission, (2011), *Roadmap to a Single European Transport Area - Towards a competitive and resource-efficient transport system*, Brussels. https://doi.org/10.2832/30955

Eurostat (2016a)," Passenger cars in the EU". Retrieved September 20, 2018, from https://ec.europa.eu/eurostat/statistics-explained/index.php/Passenger_cars_in_the_EU

Eurostat (2016b), "Freight transport statistics - Statistics Explained", Retrieved September 19, 2018, from https://ec.europa.eu/eurostat/statistics-explained/index.php/ Freight_transport_statistics#Modal_split

Federal Reserve Bank of St. Louis, (2018), "FRED Graph". Retrieved August 30, 2018, from https://fred.stlouisfed.org/graph/?g=l1r8

Heid, B., R. Hensley, S. Knupfer, and A. Tschiesner, (2017), "What's sparking electric-vehicle adoption in the truck industry? | McKinsey". Retrieved November 7, 2018, from https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/whats-sparking-electric-vehicle-adoption-in-the-truck-industry

Hirsh, J., (2018), "Daimler Unveils Electric Freightliner Cascadia". Retrieved November 8, 2018, from https://www.trucks.com/2018/06/06/daimler-unveils-electric-freightliner-cascadia/

Holguín-Veras, J., T. Encarnación, C. A. González-Calderón, J. Winebrake, C. Wang, S. Kyle, R. Garrido, (2016), "Direct impacts of off-hour deliveries on urban freight emissions", *Transportation Research Part D*. https://doi.org/10.1016/j.trd.2016.10.013

Howell, D., S. Boyd, B. Cunningham, S. Gillard, L. Slezak, S. Ahmed, J. Zhang, (2017), *Enabling Fast Charging: A Technology Gap Assessment*,. Retrieved from https://www.energy.gov/sites/prod/files/2017/10/f38/XFC Technology Gap Assessment Report_FINAL_10202017.pdf

IDDR, Sustainable Development Solutions Network, U. E. I., (2015), *Pathways to deep decarbonization in the United Kingdom*,. Retrieved from http://www.ucl.ac.uk/energy

IEA, (2017), *The Future of Trucks Implications for energy and the environment Second edition*, Paris. Retrieved from www.iea.org/t&c/

International Council on Clean Transportation, T., (2018), *CO2 emissions and fuel consumption standards for heavy-duty vehicles in the European Union*,. Retrieved from http://eur-lex.europa.eu/legal-content/

ITF, (2011), *Moving Freight with Better Trucks Research Report*, Paris. https://doi.org/10.1787/9789282102961-en

ITF, (2017a), *ITF Transport Outlook 2017*, OECD. https://doi.org/10.1787/9789282108000-en

ITF, (2017b), *Managing the Transition to Driverless Road Freight Transport*, Paris. Retrieved from www.itf-oecd.org

ITF, (2018a), "Decarbonising Road Freight Transport Workshop". Retrieved October 22, 2018, from https://www.itf-oecd.org/decarbonising-road-freight-transport-workshop

ITF, (2018b), *Decarbonising Maritime Transport Pathways to zero-carbon shipping by 2035*,. Retrieved from www.itf-oecd.org

ITF, (2018c), *Policy Priorities for Decarbonising Urban Passenger Transport*, Paris. Retrieved from www.itf-oecd.org

J. Coren, M., (2018), "One city in China has more electric buses than all of America's biggest cities have buses". Retrieved November 7, 2018, from https://qz.com/1169690/shenzhen-in-china-has-16359-electric-buses-more-than-americas-biggest-citiess-conventional-bus-fleet/

Jacob, B. and M. Caso Florez, (2018), "Electric Road Systems : PIARC Special Project". Retrieved from https://www.itf-oecd.org/electric-road-systems-piarc-special-project

Kasten, P., M. Mottschall, W. Köppel, and C. Degünther, (2016), *Erarbeitung einer fachlichen Strategie zur Energieversorgung des Verkehrs bis zum Jahr 2050 Endbericht*,. Retrieved from https://www.umweltbundesamt.de/sites/default/files/medien/377/publikationen/2016-11-10_endbericht_energieversorgung_des_verkehrs_2050_final.pdf

Kühnel, S., F. Hacker, and G. Wolf, (2018), *Oberleitungs-Lkw im Kontext weiterer Antriebs-und Energieversorgungsoptionen für den Straßengüterfernverkehr*, Berlin. Retrieved from www.oeko.de

La Rovere, E. L., A. S. Pereira, and A. F. Simões, (2011), "Biofuels and Sustainable Energy Development in Brazil", *World Development*, Vol. 39/6, pp. 1026–1036. https://doi.org/10.1016/J.WORLDDEV.2010.01.004

Lambert, F., (2018), "Tesla Semi is not scaring Daimler, CEO throws cold water". Retrieved November 7, 2018, from https://electrek.co/2018/11/05/tesla-semi-daimler-ceo-electric-trucks/

Landschützer, C., F. Ehrentraut, and D. Jodin, (2015), "Containers for the Physical Internet: requirements and engineering design related to FMCG logistics", *Logistics Research*, Vol. 8/1, pp. 8. https://doi.org/10.1007/s12159-015-0126-3

Liimatainen, H. and L. Nykänen, (2016), *IMPACTS OF INCREASING MAXIMUM TRUCK WEIGHT-CASE FINLAND*,. Retrieved from http://www.tut.fi/verne/aineisto/LiimatainenNykänen.pdf

Macedo, M. N., R. S. DeFries, D. C. Morton, C. M. Stickler, G. L. Galford, and Y. E. Shimabukuro, (2012), "Decoupling of deforestation and soy production in the southern Amazon during the late 2000s.", *Proceedings of the National Academy of Sciences of the United States of America*, Vol. 109/4, pp. 1341–6. https://doi.org/10.1073/pnas.1111374109

McKinnon, A. C., (2016), "Freight Transport Deceleration: Its Possible Contribution to the Decarbonisation of Logistics", *Transport Reviews*, Vol. 36/4, pp. 418–436. https://doi.org/10.1080/01441647.2015.1137992

McKinnon, A. C., (2018), *Decarbonizing logistics: Distributing goods in a low-carbon world*, Kogan Page, London.

Meszler, D., O. Delgado, F. Rodríguez, and R. Muncrief, (2018), *EUROPEAN HEAVY-DUTY VEHICLES: COST-EFFECTIVENESS OF FUEL-EFFICIENCY TECHNOLOGIES FOR LONG-HAUL TRACTOR-TRAILERS IN THE 2025-2030 TIMEFRAME*,. Retrieved from www.theicct.org

Meyer, T., (2018), "Disruptive Innovations for Sustainable Freight Transport". Retrieved November 16, 2018, from https://www.itf-oecd.org/disruptive-innovations-sustainable-freight-transport

Miller, J. and L. Jin, (2018), *Global progress toward soot-free diesel vehicles in 2018*, Washington. Retrieved from www.theicct.org

Mizan, T., (2018), "Alternative Fuels presentation". Retrieved from https://www.itf-oecd.org/alternative-fuels

Morris, C., (2013), "Grocery chain tests 18-ton Swiss-built electric truck". Retrieved November 7, 2018, from https://chargedevs.com/newswire/grocery-chain-tests-18-ton-swiss-built-electric-truck/

Moultak, M., N. Lutsey, D. H. Beijing, | Berlin, and | Brussels, (2017), *TRANSITIONING TO ZERO-EMISSION HEAVY-DUTY FREIGHT VEHICLES ACKNOWLEDGMENTS*,. Retrieved from www.theicct.org

Muncrief, R. and B. Sharpe, (2015), *overview of the heavy-duty vehicle market and co 2 emissions in the european Union*,. Retrieved from www.theicct.org

Nepstad, D., D. McGrath, C. Stickler, A. Alencar, A. Azevedo, B. Swette, … L. Hess, (2014), "Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains", *Science*, Vol. 344/6188, pp. 1118–1123. https://doi.org/10.1126/science.1248525

OECD, WTO, and UNCTAD, (2018), *REPORTS ON G20 TRADE AND INVESTMENT MEASURES*,. Retrieved from http://www.oecd.org/daf/inv/investment-policy/19th-Report-on-G20-Trade-and-Investment-Measures.pdf

Pålsson, H. and H. Sternberg, (2018), "LRN 2016 SPECIAL – high capacity vehicles and modal shift from rail to road: combining macro and micro analyses", *International Journal of Logistics Research and Applications*, Vol. 21/2, pp. 115–132. https://doi.org/10.1080/13675567.2018.1430232

Panteia, (2018), *Cost comparison and cost developments in the European road haulage sector*, Zoetermeer, Netherlands.

Pettersson, J., M. Lindgren, A. Berndtsson, V. Viklund, M. Andersson, Å. Öhrnberg, … A.-K. G. Andersson, (2017), *National roadmap for electric road systems*,. Retrieved from https://www.trafikverket.se/contentassets/4c00abedf6794077a1e2a443cde60349/national_roadmap_for_electric_road_systems_20171129_eng.pdf

Reuters, (2018), "Anheuser-Busch orders up to 800 hydrogen-fueled big rigs". Retrieved October 24, 2018, from https://www.reuters.com/article/us-ab-inbev-orders-nikola/anheuser-busch-orders-up-to-800-hydrogen-fueled-big-rigs-idUSKBN1I41JI

Rothkopf, G., (2008), "BRAZIL", In *A Blueprint for Green Energy in the Americas* Inter-American Development. Retrieved from http://idbdocs.iadb.org/wsdocs/getdocument.aspx?docnum=945774

Route Monkey and WBCSD, (2016), *Demonstrating the GHG reduction potential of asset sharing, asset optimization and other measures*,. Retrieved from https://docs.wbcsd.org/2016/11/RoadFreightLab_Report.pdf

Sánchez-Díaz, I., P. Georén, and M. Brolinson, (2017), "Shifting urban freight deliveries to the off-peak hours: a review of theory and practice", *Transport Reviews*, Vol. 37/4, pp. 521–543. https://doi.org/10.1080/01441647.2016.1254691

Schroeder, J., (2010), "EPA Deems Sugarcane Ethanol an Advanced Biofuel". Retrieved November 8, 2018, from http://energy.agwired.com/2010/02/04/epa-deems-sugarcane-ethanol-an-advanced-biofuel/

Searle, S., C. Baldino, and N. Pavlenko, (2018), *What is the role for renewable methane in European decarbonization?*,. Retrieved from https://www.theicct.org/sites/default/files/publications/Role_Renewable_Methane_EU_20181016.pdf

Sharpe, B., (2017), *Barriers to the adoption of fuel-saving technologies in the trucking sector*,. Retrieved from www.theicct.org

Shindell, D., F. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, … P. Midgley, (2013), "Anthropogenic and Natural Radiative Forcing", In T. F. Stocker, P. D. Qin, G.-K., M. Tignor, S.K. Allen, J. Boschung, A. Nauels, … P.M. Midgley (Eds.), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Retrieved from https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf

Sripad, S. and V. Viswanathan, (2017), "Performance Metrics Required of Next-Generation Batteries to Make a Practical Electric Semi Truck", *ACS Energy Letters*, Vol. 2/7, pp. 1669–1673. https://doi.org/10.1021/acsenergylett.7b00432

Sundelin, H., A.-C. Mellquist, M. Linder, M. Gustavsson, C. Börjesson, and S. Pettersson, (2018), "Business case for electric roads", In *Proceedings of 7th Transport Research Arena TRA 2018* TRA2018, Vienna. Retrieved from https://www.viktoria.se/publications/business-case-for-electric-roads

Tavasszy, L. A. and J. van Meijeren, (2011), *Modal Shift Target for Freight Transport Above 300 km: An Assessment*,. Retrieved from https://www.acea.be/uploads/publications/SAG_17.pdf

Tesla, (2017), "Tesla semi". Retrieved November 8, 2018, from https://www.tesla.com/semi

The Guardian, (2015), "UK cancels pioneering £1bn carbon capture and storage competition". Retrieved November 8, 2018, from https://www.theguardian.com/environment/2015/nov/25/uk-cancels-pioneering-1bn-carbon-capture-and-storage-competition

Transport & Environment, (2016a), "20 years of truck CO2 progress - revisited". Retrieved August 17, 2018, from https://www.transportenvironment.org/newsroom/blog/20-years-truck-co2-progress-revisited

Transport & Environment, (2016b), *20 years of truck fuel efficiency-what progress? methodological note*,. Retrieved from http://ec.europa.eu/clima/policies/transport/vehicles/heavy/docs/com_285_2014_en.pdf

Transport & Environment, (2018a), *7 facts about palm oil biodiesel - And why EU policy support must end*, Brussels. Retrieved from https://www.transportenvironment.org/sites/te/files/Factsheet palm oil biofuels TE May 2018.pdf

Transport & Environment, (2018b), *CNG and LNG for vehicles and ships-the facts*, Brussels. Retrieved from www.transportenvironment.org

Transport & Mobility Leuven, (2017), *Commercial Vehicle of the Future A roadmap towards fully sustainable truck operations*,. Retrieved from https://www.iru.org/sites/default/files/2017-07/iru-report-commercial-vehicle-of-the-future-en V2.pdf

Transport & Mobility Leuven, (2018), *Exploratory assessment of the potential of road transport infrastructure policy measures to reduce transport CO2 emissions*, Leuven, Belgium. Retrieved from file:///S:/Decarbonising Transport/Road Freight Workshop/Report/Comments/180119_finalreport.pdf

Valin, H., D. Peters, M. van den Berg, S. Frank, P. Havlik, N. Forsell, … F. Di Fulvio, (2015), "The land use change impact of biofuels consumed in the EU: Quantification of area and greenhouse gas impacts". Retrieved from http://pure.iiasa.ac.at/id/eprint/12310/

Verkehrswende, A. and A. Energiewende, (2018), *The Future Cost of Electricity-Based Synthetic Fuels STUDY*, Berlin. Retrieved from www.agora-verkehrswende.de

Vermeulen, R. J., R. Verbeek, S. van Goethem, and R. T. M. Smokers, (2017), "Emissions testing of two Euro VI LNG heavy-duty vehicles in the Netherlands: tank-to-wheel emissions". Retrieved from https://repository.tudelft.nl/view/tno/uuid%3A4b1cb389-868b-4a0c-91e2-81599242db5c

Winder, A., (2016), *ITS for Commercial Vehicles Study of the scope of Intelligent Transport Systems for reducing CO 2 emissions and increasing safety of heavy goods vehicles, buses and coaches*, Brussels. Retrieved from http://erticonetwork.com/wp-content/uploads/2016/09/ITS4CV-Report-final-2016-09-09.pdf

Towards Road Freight Decarbonisation

This report identifies proven measures that decrease road freight's CO_2 emissions. Goods transport by road consumes around 50% of all diesel fuel and accounts for 80% of the global net increase in diesel use since 2000. Projections see road freight activity at least doubling to 2050, offsetting efficiency gains and increasing road freight CO_2 emissions. The report highlights policy areas that need adjustment for effective decarbonisation of road freight and points to fields where more robust evidence through further research is needed. It collects insights held at a workshop organised by the International Transport Forum in June 2018 in Paris and features the results of a survey among experts.

This report is part of the International Transport Forum's Case-Specific Policy Analysis series. These are topical studies on specific issues carried out by the ITF in agreement with local institutions.

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