WORKING PAPER 23

LOW CARBON GLOBAL ROAD FREIGHT: MOVING BEYOND FUEL ECONOMY STANDARDS

GLOBAL FUEL ECONOMY INITIATIVE
FOR ZERO CARBON VEHICLES BY 2050

International Transport Forum

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1. Introduction

Freight transport has been growing exponentially since the 1950s and as international trade is expected to continue to increase for the next few decades, despite the short-term impact of the Covid-19 pandemic crisis, carbon dioxide (CO_2) emissions from global freight transport, especially road freight, will become progressively high unless decarbonising measures are put in place today. Although transport restrictions to contain Covid-19 could reduce global freight transport by up to 36 percent in 2020 (ITF, 2020), road freight transport connectivity has been maintained in most countries and the sustainability and resiliency of the sector have also become priorities as countries re-open and start to develop their recovery pathways.

The growth of freight transport differs by country but in general, it is usually in line with GDP, reflecting the economy of a country or region, though there have been countries in Europe showing the decoupling of GDP and freight demand. It is expected that there will be little or no increase in greenhouse gas (GHG) emissions in OECD countries, but strong growth rates in Asian, including China, India and Southeast Asia, and Latin American countries in 2050. These trends reflect the high growth in road tonne-kilometre (tkm) in non-OECD regions, where road freight increased by over 9 percent in China and India between 2016 and 2017 (ITF, 2019). Road freight is currently the second largest contributor of global transport CO_2 emissions after passenger road transport and it has significantly higher emission levels than aviation, rail and marine bunkers combined (ITF, 2017). Road transport currently contributes 15 percent of total freight activity and 44 percent of global freight CO_2 emissions (ITF, 2021). It is also the predominant mode for freight in most countries and accounted for 28 percent of total transport energy use (IEA, 2015), while constituting around one-fifth of global oil demand (IEA, 2017a).

It is clear that road freight plays a critical role in decarbonising the transport sector across the world. Given that the use of road freight transport is an attractive mode choice due to the various benefits it could offer, including its high level of flexibility, accessibility, service and competitive cost, it is challenging to shift to other modal choices, such as rail, that could be more sustainable and resilient (ITF, 2019). Hence, appropriate policies need to be in place to increase the energy efficiency of road freight transport and to fully optimise heavy duty vehicle (HDV) operations through asset utilisation, which are two main approaches in the decarbonisation of freight transport (McKinnon, 2018) and the focus of this study. Shifting freight to lower carbon modes and switching to lower-carbon energy are two other approaches (McKinnon, 2018).

Improving freight efficiency is a direct way of reducing CO_2 emissions in a growing sector as it reduces energy intensity (megajoules per tonne-kilometre) and increases vehicle efficiency (megajoules per vehicle-kilometre). It can also improve vehicle performance, utility and safety, which are all highly valued by the consumer. In addition, energy efficient vehicles reduce transport costs, due to the lower costs of vehicle use in the long term, with a positive impact on economic productivity, since they reduce input costs for the same level of economic output. Additional positive spill over effects could be derived from policy features that support the deployment of technologies, such as electrification, that have the capacity to set in motion a virtuous self-reinforcing chain of cost reductions. For example, in the case of electrification, the cost reduction will come from battery cost reductions through economies of scale and technology development. Another advantage of using fuel economy standards to reduce CO_2 is that they can help maintain high fuel economy even when fuel prices are low and reduce the impact of fluctuating oil prices on GHG emission levels. Other policies include changes in freight policies beyond fuel economy standards, such as performance standards, e.g. tyre rolling resistance, vehicle capacity, pricing, and operational management, including the increase of vehicle load factor (McKinnon, 2005), which will all contribute to the development of a low carbon global road freight system by improving energy efficiency.

There are currently six markets, namely Canada, China, Japan, and the United States (U.S.) and more recently, India and the European Union (EU) that have existing fuel economy standards for HDVs in place. A few others, including South Korea, Mexico and Brazil are considering similar standards. The total road freight demand in these nine markets alone constituted 80 percent of global road freight demand in 2015 and will remain the vast majority (77 percent) even in 2050 (ITF, 2019) (Figure 1).

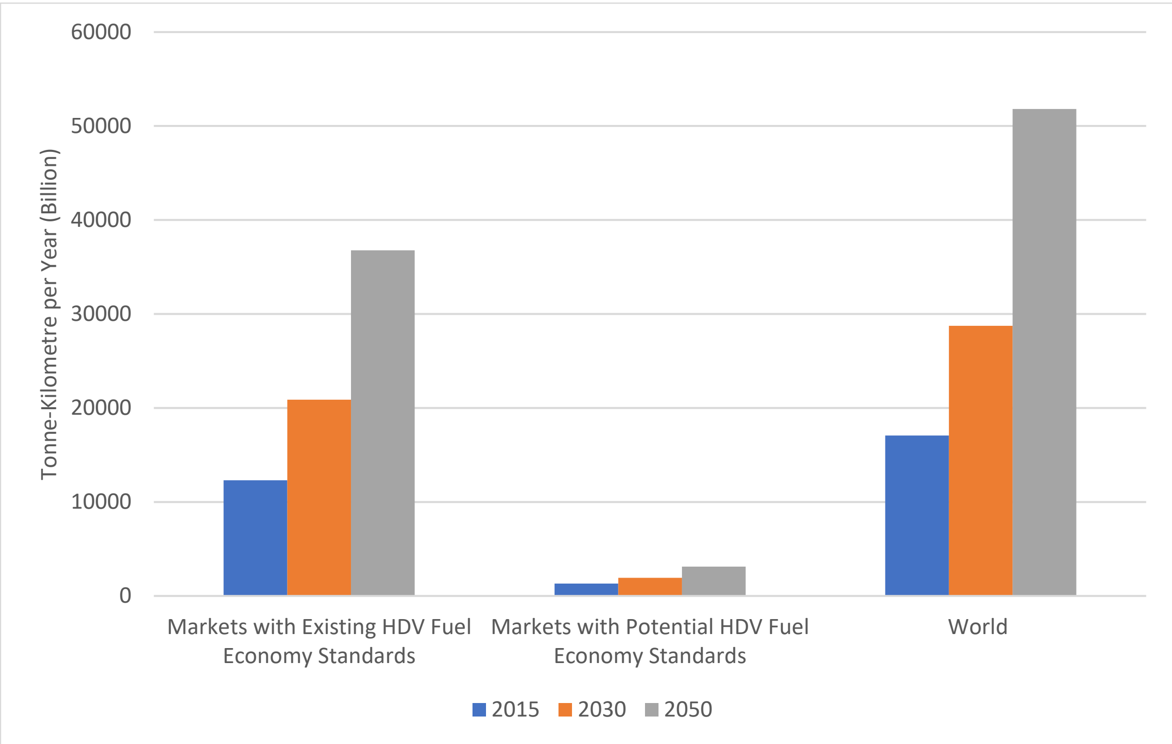

Figure 1. Total road freight transport demand in 2015, 2030 and 2050 in markets with existing (i.e. Canada, China, EU, India, Japan, and the U.S.) or potential (i.e. Brazil, Mexico and South Korea) fuel economy standards.
Data Source: ITF, 2019

These nine markets are also influential and significant in terms of the size of their vehicle fleet. In 2015, the share of medium duty vehicle (MDV) and HDV from the nine markets made up 72 percent and 57 percent of the global fleet respectively (IEA, 2019). With the expected increase in freight transport activities, the demand for global HDVs will continue to grow but policies implemented in the major markets will not only have a national impact but could also influence other markets and create regional improvements in fuel economy.

Subsequent CO_2 emissions from the same nine markets contributed to 83 percent of total global road freight CO_2 emissions in 2015 and will continue to maintain a significant share (76 percent) through 2050 under a baseline scenario with currently adopted policies (ITF, 2019). The implementation of fuel economy standards in these nine markets will thus not only increase fuel savings, it will also have a significant long-term impact on road freight CO_2 emissions.

Existing fuel economy standards differ by country and have different levels of stringency. Key differences among countries can be categorised into five main types (Atabani et al., 2011), namely:

1) Fuel efficiency approach, e.g. fuel consumption reduction or CO_2 reduction;
2) Way of measurement, e.g. mpg, g/km, km/l, l/100km, or g/mile;
3) Structure or segmentation, e.g. weight-based;
4) Testing methods, e.g. simulation or physical testing, and
5) Type or timing of implementation.

The application of standards to the articulated vehicles, only the tractor unit or to the whole vehicle will also create different impact. The achievement of targeted fuel economy standards will in fact depend on the enforcement of each of these policies.

Using road freight demand outputs from the ITF freight model (ITF, 2019), which combines both international and domestic freight, this study examines the impact of different levels of fuel economy standards in selected countries and other policies that are non-fuel or vehicle technology related on global CO_2 emissions from road freight in 2030 and 2050. Three different scenarios, as well as a baseline, are developed to evaluate the various types of policies and to help identify priorities for the road freight sector to achieve its CO_2 emission targets. This study also seeks to quantify the impact of changes in vehicle optimisation on CO_2 emission reduction and to consider the combination effect of fuel economy standards and other sustainable road freight policies, which will provide insights for countries that are developing low or zero carbon road freight transport. Although urban freight and logistics are another growing area contributing to climate change, existing technologies are already commercially viable to mitigate their impact and are more advanced than for long haul freight transport (ITF, 2018; Heid et al., 2017). They are beyond the scope of this study, which only focuses on MDVs and HDVs.

2. Policies for Reducing CO_2 Emissions in Road Freight Transport

The road freight sector, especially long haul heavy duty trucking, is one of the hardest transport sectors to abate, as zero carbon technologies are currently still unavailable commercially. However, this implies that a more robust set of road freight transport policies would be necessary to allow the sector to transition to zero carbon over time.

The successful reduction of CO_2 emissions in road freight transport requires a mix of policies that will address the fuel and vehicle energy efficiencies of HDVs, as well as operational changes that are necessary to optimise freight transport. The complexity of HDVs, contributed by the fact that most trucks are custom built on an individual basis depending on their specific use and the type of commodity transported makes it critical for CO_2 emission reduction policies to consider the key features of the vehicle, including its size, shape, combination of tractor and trailer, type of fuel used, usage pattern, i.e. duty cycle, which includes payload, speed, and road conditions (ACEA, 2017). Greater standardisation of HDVs, such as those seen in countries in Europe, can partly reflect higher integration in the EU truck manufacturing industry and will also enable the standardisation of regulations. HDVs are also distinctive by region as different standards influence vehicle design, axle loading, mass, and volume. They are also often designed according to task-specific requirements and the weight and shape of cargo to be transported. An example of HDV features and external conditions in India is shown in Box 1.

Box 1 HDV Features in India
(Contributed by John Woodrooffe, Transport Research Institute, University of Michigan)

HDVs using the regional trade corridors of Bangladesh Bhutan Nepal and India (BBIN) are generally single unit vehicles having two to four axles.

Figure 1.1. Four axle single unit truck with lift axle.
Source: Woodroffe, 2019

Articulated vehicles in the form of tractor semitrailers are present but less common. BBIN trucks are generally robust in design with rugged steel spring suspensions specifically selected to handle substantial overload conditions. It is well known that steel spring suspensions are highly reactive generating large dynamic loads which negatively impact pavements and bridges. Truck fleets in BBIN are very different than those found in developed countries, both in terms of vehicle configuration, average vehicle age and general fitness. There appears to be a large gap between regulations governing safety and vehicle mass limits and the level of effective compliance with these standards. Given their overall mass and dimensions, HDVs are largely incompatible with the narrow road environments strongly supporting the need for infrastructure upgrades and related safety enhancement efforts. There are opportunities for the harmonisation of regional truck configurations and vehicle operation arrangements. The potential for improvements in freight productivity and transport CO_2 reduction is considerable within BBIN, through infrastructure investment, the use of high productivity vehicles and policy options that improve freight transport efficiency.

Observations of heavy trucks and motor coaches operating on the rural roads revealed that they were incompatible with the road design particularly with respect to lane width and proximity of dwellings and vulnerable road users to the roadway. The roads are simply too narrow for trucks and busses to operate safely. Due to limited road width, suboptimal road conditions, road user speed differential, congestion and traffic calming road bumps, the mean speed of traffic flow on the observed roads is very low (in the range of 20 to 30 km/h), though the average speed of trucks could be higher in different cities in India (Statista, 2021).

2.1. Fuel Economy Standards

One of the most effective ways to reduce road freight CO_2 emissions is the implementation of fuel economy standards, as the amount of tank-to-wheel CO_2 emissions emitted is directly related to the amount of fuel consumed. Fuel economy, also known as fuel efficiency, is a measure of how far a vehicle can travel per unit of fuel, e.g. kilometres per litre (km/l) or litres of fuel per 100km and it reflects the relationship between distance travelled and the fuel consumed. Regulatory pressure to improve the fuel economy of vehicles can also trigger improvements in vehicle technology, such as aerodynamic characteristics and low rolling resistance tyres, to increase fuel economy and hence, reduce energy use and CO_2 emissions per km.

Existing fuel economy standards have different approaches too. For example, Japan and China's fuel economy standards for HDVs include engines, drive trains, aerodynamics, and tyres, while standards in the U.S. and Canada have a wider scope that include weight and auxiliary power units, besides engines, drive trains, aerodynamics, and tyres.

2.1.1 Japan

Japan for instance adopted a top runner approach, where the average fuel economy must be higher than for the best model in the base year (2002), by the target year 2015. Targets are disaggregated by vehicle type, class and weight. If the targets are met, the fleet average fuel economy for trucks would have a 12 percent improvement over 2002 performance. In March 2019, the Ministry of Economy, Trade and Industry (METI) and the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) introduced new fuel economy standards for heavy vehicles running on diesel, including trucks and buses. This regulation applies to vehicles with a total weight of more than 3.5 tonnes and new trucks and other heavy duty vehicles are expected to have a fuel economy of 7.63 kilometres per litre (km/L) by 2025 (implying an efficiency improvement of 13.4 percent relative to the 2015 standards), and a level of 6.52 km/L for buses by 2025 (implying an efficiency improvement of 13.4 percent relative to the 2015 standards) (METI, 2019; IEA 2019).

2.1.2 U.S. and Canada

In the U.S. and Canada, both vehicle (including design) and engine emissions are regulated. Significant process has been made in the U.S. in 2021, when the U.S. Environment Protection Agency (EPA) announced plans to reduce GHG emissions and other air pollutants from HDVs through a series of rulemakings over the next three years. The first rulemaking will be finalised in 2022 and will apply to HDVs starting in model year 2027. EPA started regulating GHG emissions and fuel economy standards for MDVs and HDVs in models years 2014 - 2018 (Phase 1). Required CO_2 and fuel consumption reductions vary by vehicle type and range from 6 - 23 percent compared to a model year 2010 baseline (TransportPolicy, 2018a). The success of the Phase 1 standards led to Phase 2 standards in 2016 for MDVs and HDVs through model year 2027 that will improve fuel efficiency and reduce carbon emissions to reduce the impacts of climate change, while bolstering energy security and spurring manufacturing innovation (EPA, 2021). Phase 2 standards are applicable for 2018–2027 and are estimated to reduce CO_2 and fuel consumption by 16 percent for heavy-duty pickup trucks and vans, 16 - 19 percent for vocational vehicles, and up to 30 percent for tractor-trailers (TransportPolicy, 2018a). The U.S. also uses the Greenhouse Gas Emissions Model (GEM), which is a vehicle simulation tool, for MDV and HDV compliance. GEM estimates GHG emissions and fuel efficiency performance of specific aspects of HDVs, which include vehicle technologies or component attributes that affect CO_2 emissions and fuel use, such as aerodynamic performance, tire rolling resistance, vehicle weight, engine fuel map, transmission gear ratios, tire radius, or axle ratio (EPA, 2020).

HDV and engine GHG emission regulations in Canada were updated in 2018, adopting U.S. HDV Phase 2 equivalent standards. Canada's HDV emissions regulations will reduce greenhouse gases from on-road HDVs, engines, and trailers. The regulations will introduce stronger standards for vehicles and engines in model year 2021, and they will increase in stringency up to model year 2027 to give heavy-duty vehicle manufacturers and owners time to adapt (Government of Canada, 2018). Once the regulations are fully phased in, some vehicle-types can expect CO_2 reductions of up to 25 percent from model year 2027 HDVs. Phase 2 regulations follow the Phase 1 regulation, which was finalised in 2013 and affected commercial vehicles between 2014 and 2017, and were adopted in 2018 (Government of Canada, 2018). Canada's GHG emission standard for HDVs is closely aligned with the U.S. HDV fuel consumption and GHG standards. However, the U.S. standard is a joint fuel consumption and GHG emission standard, whereas the Canadian standard only covers GHG regulation. The standard requires CO_2 emission reductions ranging from 6 to 23 percent in the model year 2017 timeframe (TransportPolicy, 2018; ICCT, 2018).

2.1.3 China

China's standards are weight based and also include both heavy duty diesel and gasoline vehicles. There are currently two stages of implementation. Stage 1 proposed an industry standard for all new HDVs, Stage 2 is a national standard, which reflects a tighter limit by an average of 10.5 to 14.5 percent compared to Stage 1, while Stage 3 National Standard tightens fuel consumption limits for new tractors, trucks and buses by 15.3 percent, 13.8 percent and 15.9 percent respectively, compared to the previous Stage 2 Standard. The Stage 3 standard also apply to all new heavy commercial vehicles starting from July 2021 (National Standards of China, 2018). The goal of Stage 3 standard is to reduce fuel consumption by approximately 15 percent in 2020 from the 2015 levels (ICCT, 2016)

2.1.4 EU

The first CO_2 standards for HDVs intended for the delivery of goods in the EU was proposed in 2018 and adopted in 2019, which aim to reduce the average CO_2 emissions from new HDVs by 15 percent in 2025 and by 30 percent in 2030, compared to 2019. The metric used for the HDV CO_2 standards in the EU, i.e. the average specific CO_2 emissions, are measured in grams of CO_2 per tonne-kilometre (gCO_2/t-km) (ICCT, 2017a). CO_2 emissions and fuel consumption data determined with the Vehicle Energy Consumption Calculation Tool (VECTO), which is a simulation tool that has been developed explicitly to enable this regulatory development. The European scheme includes incentives allowing manufacturers that reach two percent market share of zero- and low-emission vehicles to benefit from a relaxed stringency of the overall CO_2 emissions standards, and allows for the use of super credits to meet the 2 percent market share threshold, but only in 2025. This is one of the elements expected to start facilitating the deployment of zero-carbon enabling technologies for freight transport in the longer term.

2.1.5 India

Regulators in India are also working toward an India-specific version of the European Commission's VECTO, which is known as the Bharat Energy Efficiency Tool (BEET), and its use in future fuel efficiency regulations that would allow India to implement simulation-based standards that are more aligned with trends in other major vehicle markets (ICCT, 2019). In India, fuel economy standards are in place for commercial HDVs with a gross vehicle weight of 12 tonnes or greater with diesel engines. Two sets of standards have been published. Phase 1 standards have been effective as 1 April 2018, while Phase 2 standards have been effective as 1 April 2021 (ICCT, 2017c). The regulations are aimed at reducing fuel consumption and GHG emissions from diesel-powered trucks and buses with a gross vehicle weight of 12 tonnes or greater. Indian HDVs greater than 12 tonnes represent about 60 percent of total fuel use and GHG emissions from the entire HDV fleet. The standards are a minimum performance requirement, similar to the existing Bharat Stage (BS) emission norms. Each vehicle model and configuration need to comply with required fuel consumption levels, which is a different approach from fuel consumption and greenhouse gas (GHG) standards in the U.S. and Canada that are based on sales-weighted averaging (ICCT, 2017a).

Fuel economy standards are capable of triggering improvements in vehicle technologies (OECD, 2011) but as different technology improvements have different impacts on fuel economy, energy savings will vary based on mission profiles. For example, improvements to engine efficiency were estimated to lead to a 4 – 18 percent increase of fuel economy, depending whether they are used for local or long haul freight transport in the short term (TIAX, 2011; Schroten, Warringa and Bles, 2012). Improvements in aerodynamics could lead to up to 20 percent reduction in fuel consumption (Freight Best Practice Programme, 2006) and are especially relevant for in highway driving. Advancing tyre technologies can also reduce CO_2 emissions in the road freight sector by up to 5 percent (Breemersch and Akkermans, 2018). A 10 percent reduction in rolling resistance could generate a fuel saving of approximately 3 percent in general (Schmidt and Dyre, 2012; Hammerstrom et al., 2008). Further savings can be enabled by weight reduction, especially in urban driving cycles.

When they are designed to spur the deployment of novel technologies, fuel economy standards also have the unique capacity to set in motion a virtuous self-reinforcing chain of cost reductions. A key example is the case of powertrain electrification, since it can induce battery cost reductions through scale and technology development, increasing the cost competitiveness of the technology and widening the scope of its adoption.

2.2. Other Policies

Although fuel economy standards are effective in reducing fuel consumption and CO_2 emissions directly, they only apply to new vehicles and not existing vehicle fleets. Other policies would still need to be implemented in order to regulate and improve the performance of existing vehicle fleets. Such policies include influencing key freight parameters in addition to fuel economy, such as the spatial structure of the supply chain, freight modal split, vehicle routing, vehicle utilisation, exposure to congestion, and the carbon intensity of energy source (McKinnon, 2015). Policies that could influence these parameters include land use planning, infrastructure investment in alternative modes, modal transfer grants, truck routing schemes, road pricing, improved vehicle design, vehicle size and weight regulations, changes in night delivery restrictions, and the support for alternative fuels (McKinnon, 2015). In addition to road pricing, other fiscal policies that are effective in reducing freight transport CO_2 emissions include fuel, registration and carbon tax, distance based charging (Rivers and Schaufele, 2015; ITF, 2018), as well as subsidies that will encourage cleaner and more efficient vehicle technologies or feebates. Feebates serve as a fee on inefficient technology and a rebate on efficient vehicles, which will encourage both the demand for and design and manufacture of more efficient vehicles (ICCT, 2010).

Drivers training can also lead to eco-driving, which, for combustion engines, has shown to reduce fuel consumption by up to 12 percent, with an average of 7 percent (Greening et al., 2015) in the UK. The scope for savings due to eco-driving also exists for electric and hybrid vehicles, but it is less relevant due to the possibility to recover energy while braking and the high efficiency of electric motors across all driving conditions.

The operational aspects of HDVs for road freight are also as important as changes in vehicle technology. Operational policies can be defined by those concerning the productivity of operations, which is defined as the ratio of outputs (such as tonne-kms or vehicle-kms) to inputs (such as fuel, vehicles or labour). Caplice and Sheffi (1994) described this as "transformational efficiency", as it measures the efficiency with which a resource is converted into an activity. Operational policies can also change the utilisation of HDVs, which is the ratio of the capacity actually used to the total capacity available (such as the amount of space in a container actually occupied by a load) (Caplice and Sheffi, 1994) and in other words, the load factor. The load factor is not just constrained by maximum weight but also by the volumetric capacity of a vehicle, which will determine the amount of freight that the vehicle can accommodate. This is especially relevant for low density goods, where volumetric capacity is more appropriate to determine load factor (McKinnon, 2018). Empty running currently accounts for approximately a quarter to a third of truck-km (McKinnon, 2018). This figure varies significantly by country and the average for EU countries is approximately 23 percent, with a range between 10 to more than 40 percent (Eurostat, 2020). In the U.S., approximately 18 to 21 percent of trucks run empty (ATRI, 2016; SmartWay, 2015), while for developing Asian and Latin American countries, the average percentage of empty runs was 30 and 43 percent respectively (Transport Research Support, 2009; IADB, 2015).

In addition, the de-speeding of logistics, reducing the speed at which products flow through the supply chain will also have a significant impact on fuel consumptions and subsequent CO_2 emissions (McKinnon, 2016). A truck travelling at 105 km per hour rather than 121 km per hour could use 27 percent less fuel (Garthwaite, 2012). Reducing the maximum speed from 105 km per hour to 97 km per hour also yielded the greatest fuel saving of around 7.7 percent (Ang-Olson and Schroeer, 2002).

3. Methodology

Using the ITF freight model (ITF, 2019), which includes both international and domestic freight demand outputs, and energy and fuel mix assumptions from the International Energy Agency's (IEA) Mobility Model (MoMo), this study evaluates the impact of two main groups of low carbon freight transport policies, 1) fuel economy standards and 2) non-fuel or non-vehicle technology related policies, specifically vehicle optimisation in terms of load factor and route optimisation, on CO_2 emission projections in 2030 and 2050. There are many other non-fuel or vehicle technology related policies that have been shown to effectively reduce HDV CO_2 emissions, such as driver training and assisted driving, high capacity vehicles, physical internet, truck platooning, digital freight matching, and widening of delivery windows (ITF, 2018; McKinnon, 2018; IEA, 2017a). However, vehicle and route optimisation policies were selected in this study because of their considerable impact on system efficiency and CO_2 emissions reduction, as well as the feasibility of implementation in both developed and developing countries. Four different policies scenarios are then developed to evaluate these two different groups of policies separately and combined. As the focus is on HDVs, urban freight transport is excluded in the analysis.

3.1 Freight Transport Demand

The freight transport demand values, both in the form of tonne-kilometre (tkm) and vehicle-kilometre (vkm) used in this study were derived from the ITF freight model. The ITF freight model assesses and provides scenario forecasts for freight flows around the world. It is a network model that assigns freight flows on all major transport modes to specific routes, modes, and network links. Centroids, connected by network links, represent zones, i.e. countries or their administrative units, where goods are consumed or produced (ITF, 2020). The current version of the model estimates freight transport activity for 19 commodities for all major transport modes including sea, road, rail, air and inland waterways. The underlying network contains 8 437 centroids, where consumption and production of goods takes place. Of these centroids, 1 134 represent the origins and destinations (ODs) for international trade flows, and 7303 represent the ODs of domestic flows. Each of the 152 863 links of the network is described by several attributes, including length, capacity, travel time (including border crossing times), and travel costs (per tkm) (ITF, 2020).

Freight demand is then derived using three categories of inputs, namely, trade forecast data, network data by mode, and economic, demographic and geographical data. Trade forecast data, which are used to derive freight flows and subsequent freight transport demand, are collected from the OECD's ENV-Linkages Computable General Equilibrium (CGE) model, which is a global economic model that illustrates how economic activities are inter-linked across several macroeconomic sectors and regions. The model projects international trade flows in values for 26 regions and 25 commodities up to 2060 (Château et al., 2014). Out of the 25 commodities, 19 commodities are relevant to transport.

Another key input to the ITF freight model is network data, based on open GIS data source for different transport modes. The ITF has consolidated and integrated different modal networks into a single routable freight network. Transport links between centroids are developed using data on intermodal dwelling times to create networks that are composed of different modes. Each link in the network varies by length, capacity, maximum speed, cost, travel times, and border crossing time (where applicable) (ITF, 2020). Economic and demographic data include population (UN, 2017) and GDP data for regions (OECD, 2018) associated with each centroid. The economic characteristics of each report also reflect data on the contribution of the main sectors of the economy to the GDP (ITF, 2020).

The ITF freight model provides tkm and vkm estimates for each link and node in the freight network, disaggregated by transport mode and by commodity type (ITF, 2020). This allows the estimation of corresponding values for different origin-destination pairs and for single mode or multi-modal routes. These outputs can then be further aggregated on a country or regional level. The results can also be grouped by origin or destination, estimating the total volume of cargo leaving or coming to a centroid or node. The model provides throughput for each port and airport, as well as for each border crossing point. For the purpose of this study, only road freight transport tkm and vkm values are included in the analysis. These values are also aggregated by country as defined by the International Standard for country codes (ISO), which are then used as inputs in the energy use and CO_2 emission modelling framework developed for this specific study, as further described in Section 3.2.

As the ITF freight model currently does not include any variation in vehicle size, this study uses the IEA's definition of vehicle categories to determine tkm and vkm by vehicle type, i.e. medium freight trucks (MFTs) and heavy freight trucks (HFTs) (IEA, 2017a). The gross vehicle weight for MFTs is between 3.5 and 15 tonnes, while vehicles with a gross vehicle weight greater than 15 tonnes are categorised as HDVs (IEA, 2017a). Both MFTs and HFTs are considered as HDVs and are used in long haul freight transport. The average vehicle fleet turnover rates assumed in this study are also based on the IEA's assumptions, which vary by country, ranging from 10 to more than 15 years, with the global average of 13.99 years for MFTs and 14.19 years for HFTs (IEA, 2017a).

Small trucks or light commercial vehicles (LCVs) are excluded in the analysis due to the scope of this study, which is focused on fuel economy standards for HDVs. The load factors used in this study are consistent with the values derived from the ITF's freight model (ITF, 2019).

3.2 Energy Use and CO_2 Emission Modelling Framework

Energy use was estimated based on the IEA's approach (IEA, 2017b), which includes a detailed characterisation of vehicle technology and fuel mix, including internal combustion engines that run on gasoline, diesel, compressed natural gas (CNG) or liquid petroleum gas (LPG), gasoline hybrid, diesel hybrid, hydrogen fuel cell, hydrogen internal combustion engine hybrid, and electric motors, as well as a vehicle stock model. Related fuel options include petroleum gasoline and diesel, biofuel and synthetic fuel alternatives to liquid fuels, gaseous fuels including natural gas and hydrogen, and electricity. Total energy use (E) for vehicle type i can therefore, be estimated using the following equation (*1*).

$$E_i = \sum(I_{i\,*}\,D_i) \qquad (1)$$

where, E_i is the total energy use, I_i is the energy intensity for vehicle type i, which also reflects fuel type, and D_i is the total distance travelled by vehicle type i. Tank-to-wheel CO_2 emissions were then estimated for each fuel type using coefficients of carbon per unit of energy consumed in vehicle type i. The distance (D_i) refers to total vehicle travel (per year), as represented by vkm derived from the ITF freight model described in Section 3.1. Estimates of tkm from the ITF freight model are split by vehicle technology and fuel type according to the IEA's assumptions on the share of vehicle technology (IEA, 2017b) before converting them to vkm using load factor values from the ITF freight model (ITF, 2019) for each vehicle category.

This energy use and CO_2 emission modelling framework creates a wider range of CO_2 emission projections based on the implementation of different levels of fuel economy standards, as well as non-fuel or vehicle technology related policies across various countries and regions in the world. The CO_2 emissions estimated will show how effective fuel economy standards are in reducing global road freight emissions, independent of changes in other policies, technology, fuel type, or modal shift. This modelling framework is also applied in countries without any current HDV fuel economy standards but are considering such policies, in order to evaluate the impact of fuel economy standards on their CO_2 emissions from road freight, as well as on a global level. More details on the fuel economy improvements assumed for different countries are described in the following section.

3.3 Policy Scenarios

Four different policy scenarios are developed in this study, including:

1) A baseline scenario;
2) A robust fuel economy standards scenario ("Robust Fuel Economy Policies"), which assumes a rapid expansion of fuel economy standards to three new markets, namely Brazil, Mexico and South Korea, coupled with an increase in the rate of improvement in markets with existing HDV fuel economy standards by 2050;
3) A scenario that examines the wide adoption of non-fuel or non-vehicle technology related policies (i.e. vehicle optimisation through changes in load factors and route optimisation) ("Optimisation"), and

4) A combined set of fuel economy standards and other non-fuel or vehicle technology related policies ("Combined Policies"). Each scenario will project CO_2 emissions to 2030 and 2050, using 2015 as the base year.

The scenarios illustrate the impact of fuel economy standards on reducing global CO_2 emissions and the outputs are also compared with the Global Fuel Economy Initiative's (GFEI) "35 by 35" global target, which refers to a 35 percent reduction of fuel consumption from 2015 levels by 2035 for HDVs (GFEI, 2019).

Assumptions on fuel economy standards used in the baseline scenario are informed by the IEA's "Reference Technology Scenario", as outlined in the *Future of Trucks* report (IEA, 2017a), which takes into account of policies currently in place to limit emissions and improve energy efficiency. These assumptions are then changed accordingly in the "Robust Fuel Economy Policies" and "Combined Policies" scenarios.

In the "Robust Fuel Economy Policies" scenario, there is a strong political will in major markets to implement robust fuel economy standards. All markets that have existing HDV fuel economy standards in place, which are Canada, China, EU, India, Japan, and the U.S., will increase their fuel economy standards by up to 50 percent in 2050, while markets that are considering the implementation of fuel economy standards will do so by 2030 and further improve their fuel economy by 2050. These markets include Brazil, Mexico and South Korea, where the percentage decrease in fuel use in litre gasoline-equivalent per 100 kilometres (lge/100km) will be 50 percent by 2050 compared to 2015 levels (Table 1). This scenario assumes improvement of HDV fuel economy standards for new vehicles in the nine markets include in this study. Although imported second hand vehicles are significant in some countries, such as Mexico, they are not included within the scope of this study. This scenario assumes that there are no changes in any other policies, technology, fuel type, or modal shift, apart from fuel economy standards. Possible rebound effects due to a lower cost of driving as fuel efficiency increases are currently not captured in the ITF freight model nor in this scenario. It is also assumed that there are no changes in fuel prices and taxes between the baseline and "Robust Fuel Economy Policies" scenarios.

The "Optimisation" scenario presents a different approach to achieve low carbon global road freight. This scenario, which focuses on increasing system efficiency instead of depending on improvements and expansion of fuel economy standards, explores the impact of non-fuel and non-vehicle technology related policies that will lead to changes in the average load factor, distance travelled (vkm) and fuel use. These policies include vehicle optimisation through changes in load factor and route optimisation. Vehicle and route optimisation are enhanced through the use of innovative digitalisation, where vehicle routing and scheduling are extensively commercialised globally and online load matching services become a common practice. This scenario assumes that load factor will increase by 15 percent by 2030 and 30 percent by 2050, while greater efficiency in freight movement will lead to a decrease in distance travelled (vkm) by 10 and 20 percent on average in all the countries selected in this study in 2030 and 2050 respectively (Table 1). In this scenario, fuel economy standards are assumed to remain the same as in the baseline scenario. Similarly, there are no assumed changes in energy prices and taxes between scenarios.

The “Combined Policies” scenario combines improvements of fuel economy standards in markets with existing standards and expansion of fuel economy standards to more markets (“Robust Fuel Economy Policies” scenario) together with non-fuel or vehicle technology related policies (“Optimisation” scenario) to capture the cumulative impact of these different policies on the reduction of global road freight CO_2 emissions. There are no assumed changes in fuel prices and taxes.

The scenario outcomes are not predictions, but they illustrate different possible futures based on the assumptions applied. The primary interest is to identify the magnitude of different impacts. These policy impacts are evaluated by changing the relevant components (e.g. vkm or load factor) in the energy use and CO_2 emissions functions based on the assumptions indicated in the scenarios (Table 2).

Table 2. Key Assumptions for Policy Scenarios

Scenario	**Baseline**		**Robust Fuel Economy Standards**		**Optimisation**		**Combined Policies**	
Policy Assumption	2030	2050	2030	2050	2030	2050	2030	2050
Fuel Economy Standards[1]	litres of gasoline equivalent/100km		% decrease in lge/100km				% decrease in lge/100km	
Canada	22-35	18-26	30	50	22-35	18-26	30	50
China	20-30	15-23	30	50	20-30	15-23	30	50
European Union	21-32	16-24	30	50	21-32	16-24	30	50
India	21-44	16-33	30	50	21-44	16-33	30	50
Japan	22-32	17-26	30	50	22-32	17-26	30	50
United States	23-36	19-29	30	50	23-36	19-29	30	50
Brazil	25-41	18-29	30	50	25-41	18-29	30	50
Mexico	25-48	19-34	30	50	25-48	19-34	30	50
South Korea	22-33	17-24	30	50	22-33	17-24	30	50
Non-fuel and Non-vehicle Technology Policies[2]								
Vehicle Optimisation (% increase in load factor)	ITF Freight Model		ITF Freight Model		15	30	15	30
Route Optimisation (% decrease in distance travelled)	ITF Freight Model		ITF Freight Model		10	20	10	20

Note. Baseline figures of the fuel economy standards refer to the estimates of on-road fuel economy of new MDVs and HDVs derived from the IEA's New Policies Scenario (IEA, 2019) and are shown here for illustrative purposes only. The ITF Freight Model refers to the load factor and vkm assumptions made in the 2019 ITF Freight Model (ITF, 2019).

1. The fuel economy standards assumptions for 2030 somewhat reflect current ambitions in markets with existing HDV fuel economy standards. However, the assumptions in 2050 are more ambitious than current standards. Although the direct reduction of CO_2 emissions resulting from changes in fuel economy standards

depend on various factors, such as driving and road conditions, and could vary by country, the emission model used in this study showed that a 10 percent decrease in fuel economy will lead to an approximate 8.5 percent decrease in CO_2 emissions on average.
2. Non-fuel and non-vehicle technology policies include vehicle optimisation improvements, such as improvements in the spatial structure of the supply chain, vehicle routing (route optimisation), vehicle utilisation and asset sharing, and truck routing schemes, changes in night delivery restrictions, and the support for alternative fuels (McKinnon, 2015).

4. Results

The results described in this section reflect the policy scenario outcomes that are designed to illustrate the impact of different measures and they are not meant to be projections of the future. Changes in fuel use and subsequent CO_2 emissions are estimated for the baseline and three different policy scenarios based on the assumptions described in the previous section. The base year of 2015 remains consistent across all scenarios. The Baseline scenario projections are developed using fuel economy standards assumptions included in the IEA's New Policies Scenario (IEA, 2019), which reflects changes in energy efficiency over time, but distance travelled are derived from the ITF's freight models (ITF, 2019).

In the "Robust Fuel Economy Policies" scenario, which only includes changes in fuel economy standards in nine major markets, CO_2 emissions in both 2030 and 2050 decrease by approximately 9 percent and 20 percent compared to the baseline (Figure 2). In this scenario, the expansion of fuel economy standards to more markets and the adoption of more stringent fuel economy standards is insufficient to keep up with the growing freight transport demand. This scenario does not meet the GFEI HDV targets to reduce CO_2 emissions by 70 percent by 2050 (GFEI, 2019).

The "Optimisation" scenario, which only reflects changes in distance travelled and load factor due to an increase in the efficiency of the freight network and systems, shows a decrease of almost 20 percent in CO_2 emissions in 2030 and a 44 percent decrease in 2050 (Figure 2). In this scenario, emissions in 2050 will be approximately 20 percent higher than in 2015 but will be lower than in 2030.

When fuel economy standards are coupled with vehicle and route optimisation policies, as illustrated in the "Combined Policies" scenario, the total CO_2 emissions decrease by 25 percent in 2030 and 53 percent by 2050. This scenario is also the only scenario where emissions in 2050 will be similar to 2015 level.

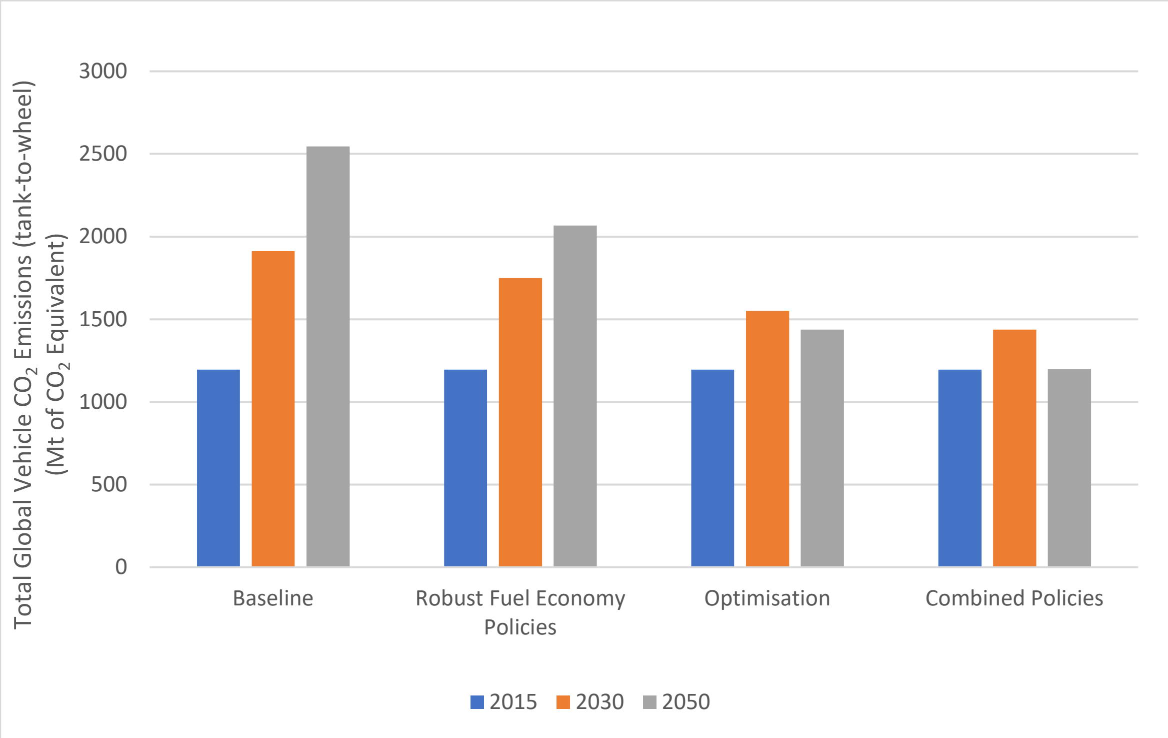

Figure 2. Total global vehicle CO_2 emissions in the baseline and three policy scenarios.

Policies that can trigger changes in load factor and distance travelled will have significant impact on CO_2 emissions, especially when they are coupled with fuel economy standards. An increase in load factor through improvements in freight transport system efficiency can complement fuel economy standards in both developing and developed markets.

This study includes selected optimisation policies in the policy scenarios and the results shown in Figure 2 indicate the need and importance to expand the range of low carbon road freight policies beyond fuel economy standards. More robust fuel economy standards need to be implemented simultaneously with measures that will also reduce distance travelled, as any improvements in fuel economy will not be strong enough to compensate for the increase in energy demand due to the growth in global freight transport demand.

The underlying assumptions of the changes in fuel economy also include the transition to electrification. However, this is based on the IEA's assumptions on the changes in the share of vehicle technology over time as described in section 3.2. No additional assumptions have been made in the policy scenarios. When improvements made in the fuel efficiency of internal combustion engines are coupled with an increased adoption of electric HDVs, the sector can then achieve the global target of "35 by 35", which refers to a 35 percent reduction of fuel consumption from 2015 levels by 2035 for HDVs (GFEI, 2019). Fuel economy standards can therefore not only promote fuel efficient vehicles but also electric vehicles and trigger the decarbonisation of vehicle fleets.

5. Discussion and Policy Insights

The growing freight transport demand in different parts of the world has presented different challenges and externalities beyond increasing CO_2 emissions. Local air pollution, congestion and linkages between freight transport networks are key priorities for many governments. Although fuel economy standards for HDVs can effectively reduce CO_2 emissions, only six markets have such standards currently. It is imperative for fuel economy standards for HDVs to be widely adopted by more markets in order to meet the goals of the Paris Agreement, as well as the GFEI's "35 by 35" targets. Existing standards also need to be further tightened as current ambitions are still not high enough to meet the targets.

The manner in which HDVs are operated is just as important as the type of vehicles used or their fuel economy. Fuel economy standards need to be coupled with other policies that will address the efficiency of the road freight transport systems and increase vehicle and route optimisation, as well as reducing empty runs. The importance of such policy improvements is that they can also help reduce costs in meeting the Paris Agreement, especially when a combination of low carbon transport policies, including fuel switching and carbon pricing, are implemented together with fuel economy standards.

This study has not considered the possibility of modal split between road and rail or other more sustainable modes for freight transport and the impact of multimodality on freight transport carbon emissions. However, even in regions with well-developed rail networks, HDVs should still be regulated through fuel economy standards and energy efficiency of road freight networks, to ensure the overall energy efficiency of the global freight system.

Three main policy insights have been identified and further described in Sections 5.1 – 5.3.

5.1 Wider Adoption of Fuel Economy Standards for HDVs

Although more countries would need to implement fuel economy standards for HDVs jointly with other policies to achieve low or zero carbon global road freight, improvements in the nine markets included in this study will already make a positive impact on reducing CO_2 emissions globally. As shown in Figure 2, when these nine markets implement and strengthen their fuel economy standards, CO_2 emissions will decrease by 20 percent compared to the baseline in 2050. More markets, especially in developing regions, would need to start designing and implementing fuel economy standards for HDVs in order to achieve an even more significant decrease in CO_2 emissions globally. An example is India, where VECTO has been adapted to the Indian truck market. In addition, the speed of adoption and the acceleration of the rate of vehicle replacement to allow more fuel efficient new HDVs more rapidly into service will also be critical in determining when CO_2 emission reduction targets can be met. In fact, fuel economy standards assumed to be implemented in the "Robust Fuel Economy Policies" and "Combined Policies" scenarios by 2050 have been moved 10 – 15 years earlier than in the baseline. More ambitious standards would need to be implemented faster to make a significant impact on CO_2 emissions reduction.

As the lack of wide adoption of fuel-saving technologies in road freight can be due to major barriers such as, the uncertainty about technology performance and return on investment, capital cost constraints, split incentives, and the lack of technology availability (ICCT, 2017b), fuel economy standards can also mitigate such barriers by increasing the certainty to both manufacturers and fleets. In addition, fuel economy standards can address the problem of uncertain technology performance and lack of technology availability as when developing fuel economy standards, regulators will usually conduct a thorough review of available and anticipated technologies and provide performance, cost and operational impact assessments (ICCT, 2017b). Such review processes will also ensure that all manufacturers are developing fuel economy technologies within the same set of standards and that efficiency technologies will be widely adopted. Standards can also be performance based and not technologically prescriptive, giving manufacturers freedom to innovate.

Moreover, fuel economy standards ensure that policy ambitions will deliver greater benefits, such as in the form of fuel cost savings, than upfront investment costs. Energy efficient vehicles reduce transport costs, given their lower total cost of ownership, with positive impact for economic productivity, since they reduce input costs for the same level of economic output. Additional positive spill overs could be derived from policy features that support the deployment of technologies (such as electrification) that have the capacity to set in motion a virtuous self-reinforcing chain of cost reductions (in the case of electrification, this comes from battery cost reductions through scale and technology development). This would then create opportunities for economic growth and industrial development and can also be framed in a broader context, where policies on fuel economy of HDVs are enforced at the same time as public procurement mandates for buses, fuel economy policies for cars and economic incentives for HDVs, especially when there is a need to close the total cost of ownership gap to enable the achievement of cost competitiveness for a given technology.

5.2 Moving Beyond Fuel Economy Standards

The implementation of fuel economy standards will not be able to keep up with the increase in freight demand and hence, CO_2 emissions, especially in developing regions where freight demand is still growing rapidly. Rebound effects induced by fuel economy standards, which is an increase in energy use as a result of lower per km fuel costs, increase in average travelling speed and power enhancements could also be as high as 30 percent (Leard et al., 2016; Galvin et al. 2021), which will need to be considered in the evaluation of the impact of fuel economy standards. In addition, fuel economy standards only apply to new vehicle fleets, which is challenging for countries with a high share of second hand HDV market and for regulating existing vehicle fleets. Countries heavily dependent on imported HDVs can thus impose a crude form of fuel economy standard on imported trucks usually based on the maximum age of the vehicle.

A comprehensive set of policies needs to be implemented in order to effectively reduce CO_2 emissions from road freight, ranging from improvements made to vehicle and fuel efficiencies and increases in the efficiency of road freight transport and logistics networks in general. This study has analysed the impact of vehicle and route optimisation, through the increase of load factor. Pricing policies can help increase the incentives to increase system efficiency and to ensure an optimal level of the use of resources (i.e. HDVs) to transport different types of commodities. With the advancement and commercialisation of digital tools, the matching of HDV drivers and shippers or carriers is increasingly automated, enabling a more efficient way for trucking and shipping companies to connect. This is especially critical in achieving a desirable load factor, as better matches also imply better loads. Policies that promote supply chain collaboration will also raise vehicle load factors. In addition, fuel switching will also be significant in reducing carbon emissions over time and can also be triggered by the implementation of fuel economy standards.

A combination of policies is required to help markets at different levels of development with varying technology availability to reduce CO_2 emissions from road freight. There are markets that will respond better to a type of policy over another and they should then identify their priority policies in the short term, mid-term and long term. For example, non-fuel or non-vehicle technology related policies will have a greater impact on CO_2 emissions reduction than the implementation of fuel economy standards in some parts of the world, while the opposite is true for others.

Collaboration between stakeholders will enhance the implementation of route and vehicle optimisation. For example, more collaboration between logistics companies can reduce emissions and save costs and the scaling up of collaboration will be critical to obtain significant decarbonisation potential (ITF, 2021). Collaboration could be further enhanced through the use of digital platforms operated by neutral, trusted third parties, which will overcome existing antitrust legislation (ITF, 2018). The Covid-19 pandemic has created an incentive to increase asset sharing between logistics companies and to increase the load factor of HDVs, which can lead to market consolidation that will support greater economies of scale for fleet renewables and rapid adoption of clean vehicle technologies (ITF, 2021).

5.3 Mainstreaming Sustainability in Freight Transport

Road freight transport is not only emitting significant amount of CO_2 emissions, it is also unsustainable in many other aspects, including the funding of new infrastructure, safety, local air pollution and congestion. The policies indicated in this study will not only reduce CO_2 emissions, they will also support the development of a more sustainable freight transport system. The mainstreaming of sustainability in freight transport in both developed and developing countries, as well as for governments and companies will be necessary to decarbonise the freight sector and for the sector to continue to serve as a trade enabler that will contribute to social and economic progress, environmental protection and climate change mitigation. Greater collaboration between stakeholder groups and between logistics companies in the supply chain will also need to take place to enhance the sharing of data, knowledge, assets and services, setting of goals and targets, and implementation of regulations. The collaboration between governments and the private sector is especially critical as there is currently a diverse mix of technological and operational measures to decarbonise road freight transport, but some are under corporate control while others require government intervention (McKinnon, 2018). Governments can take the lead in establishing data collection and information sharing platforms that to improve the efficiency of freight transport logistics through closer collaboration (IEA, 2017a). The establishment of a network of sustainable road freight initiatives and identification of leaders in green freight can also serve as examples for others (Punte and Bollee, 2017).

Mainstreaming sustainability in freight transport will need to consider the governance of the transport sector, the type of development and investment under the context of the Paris Agreement and the Sustainable Development Goals, funding availability for sustainable freight transport, engagement with the private sector, the capacity of policy makers, and the establishment of monitoring and evaluation tools to measure success and progress (UNCTAD, 2017). Fuel economy standards and non-technological policies could then fall under a broader national sustainable freight transport development plan, which would then be linked to other relevant policies within the transport sector that could ultimately trigger a systematic change.

In addition, the mainstreaming of sustainability in freight transport strategies could eventually lead to the deployment of zero-emissions truck technologies, as seen in California, where the California Air Resources Board (CARB) has incentivised the adoption of electric HDVs through pilot programmes and its Hybrid and Zero Emission Truck and Bus Voucher Incentive Project (HVIP), which provides monetary incentives for truck manufacturers to develop zero-emissions and hybrid trucks (CARB, 2017).

The importance of the sustainability of the global freight sector has also been further enhanced by the Covid-19 pandemic crisis, where transport connectivity and international movement of goods were faced with unprecedented challenges since early 2020. Different countries have reacted rapidly with evolving policy responses to maintain efficient transport connectivity while ensuring that the virus is contained but massive disruptions have been experienced. Yet at the same time, new initiatives promoting digital and paperless processes and documentation have gained traction.

As countries start to develop their recovery pathways, it is also the opportunity to improve the sustainability of freight transport vehicles, infrastructure and systems. For example, the "Covid-19 Recovery Guidelines for Resilient and Sustainable International Road Freight Transport Connectivity in ASEAN" (ASEAN, 2021), which is also included in the ASEAN Comprehensive Recovery Framework, highlighted the importance to establish regional and national transport connectivity recovery plans with a focus on resilience and sustainability. The development of a fuel economy standards roadmap for HDVs is recommended as one of the actions to support the decarbonisation of road freight transport connectivity in the guidelines (ASEAN, 2021).

Covid-19 recovery pathways that can increase the sustainability of freight operations in the mid and long term should be especially encouraged. The Covid-19 pandemic crisis has provided an opportunity to re-assess pre-Covid-19 freight transport policies and practice, and to use recovery funds to "build back better", while mainstreaming sustainability and greater resiliency in freight transport. For example, stimulus programmes can include investment in alternative fuel production, distribution and supply infrastructure, while also improving the competitiveness and availability of multimodal solutions. Incentives can be offered to encourage ready-to-implement decarbonisation solutions and fleet renewals (ITF, 2021). Regulatory changes, especially those that do not have direct costs for consumers, such as stricter fuel economy standards, are thus in the right moment to be rolled out.

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