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Review

Reviewing Truck Logistics: Solutions for Achieving Low Emission Road Freight Transport

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Abstract: Low emission logistics have become an expected and desired goal in all fields of transportation, particularly in the European Union. Heavy-duty trucks (HDTs) are significant producers of emissions and pollution in inland transports. Their role is significant, as in multimodal transport chains truck transportation is, in most cases, the only viable solution to connect hinterlands with ports. Diesel engines are the main power source of trucks and their emission efficiency is the key challenge in environmentally sound freight transportation. This review paper addresses the academic literature focusing on truck emissions. The paper relies on the preliminary hypothesis that simple single solutions are nonexistent and that there will be a collection of suggestions and solutions for improving the emission efficiency in trucks. The paper focuses on the technical properties, emission types, and fuel solutions used in freight logistics. Truck manufacturing, maintenance, and other indirect emissions like construction of road infrastructure have been excluded from this review.

Keywords: research review; trucks; logistics; emission; regulations

1. Introduction

Global pressures to decrease airborne emissions in all industrial operations are increasing. This includes freight logistics that are heavily reliant on trucks. Heavy-duty trucks (HDTs) are used in long distance hinterland transportation and, respectively, light-duty trucks (LDTs) are dominant in intra-urban transports, as they are used for the last-mile customer door-to-door deliveries. According to Mahesh et al. [1] diesel trucks contribute significantly to the total volume of traffic emissions. This leads to a deterioration of urban air quality, and several emission studies have tried to measure the actual airborne emissions from trucks. These studies often focus on cities where the air quality problems are the most tangible, e.g., [2].

Road freight transport produces increasing volumes of pollutants and emissions (e.g., dioxides; polycyclic aromatic hydrocarbons (PAH); and particulate matter (PM0.5 and PM2.5)). All of these pollutants (separately and together) have severe health impacts especially in inner cities with high density populations. They also have an increasing impact on global warming. In freight transport, the main challenge is that current truck fleets produce a high share of road traffic emissions even though their total numbers in traffic are relatively small. A number of 3.8 million heavy-duty trucks have been sold every year (globally) between the years 2011 and 2018. Almost all of them are in commercial use and fitted with diesel engines [3]. Diesel-powered engines have been the dominant choice for heavy-duty trucks for decades.

Torrey and Murray [4] referenced American Transportation Research Institute results indicating that more than 90% of road transport traffic use fossil fuels. Similarly, the U.S. Department of Transportation [5] state that trucks comprise only around 1% of on-road vehicles in 2013. The distribution of energy use by mode has remained relatively stable. In total, trucks are handling approximately 70% of all annual freight transports in the U.S. Trucks are the backbone of regional and local logistics networks in all countries, highlighting their importance in emission studies. According to Truckers report [6], one commercial truck uses up to 20,000 gallons of fuel in one year (estimated with a driving distance of 230,000 km) and a standard family car uses 500 gallons (20,000 km). These consumption numbers indicate the extent of a fuel economy that is based on current engine technologies. On one hand, they have a strong and scalable impact on all traffic emissions, and on the other, this major reason for emission growth has been well known for decades, but is complicated to tackle.

Diesel engine technology has developed extensively during the last decades. Manufacturers also use fuels that are based on renewable and recycled materials, decreasing emissions. However, emission levels have remained relatively high, and replacing engine and fuel technologies are still under development, e.g., [7–9]. One solution could be electric engine solutions, but at the moment, electric vehicles are expensive to manufacture and their purchasing prices for customers are high. Combined with a shorter operating range and a limited charging station network, they are not yet economically attractive. In the case of e-HDTs (and electric-drive cars in general) the key drivers for cost-efficiency are battery prices and developments in battery technologies. They should provide an economically feasible alternative for current diesel engines [2]. There are also production challenges (particularly batteries): Are there enough natural resources available to build such a number of battery-powered HDTs or LDTs as the future need would require? Additionally, battery-powered vehicles are not totally CO2-free over their full life-cycle due to production and maintenance requirements.

This study is a review of current academic literature on the topics of road freight-based truck emissions, pollution prevention, and mitigation solutions. The analyzed articles are limited to truck logistics that address technical engine solutions, and existing (currently used) and new fuels. It is expected that the papers provide a scattered array of solutions as has been the case in maritime studies (for corresponding literature review, see [10]). Based on these considerations, the purpose for this selective literature review is to understand: How does the selected academic literature approach and propose solutions for the mitigation of emissions from trucks in freight transport, and what are the most relevant methods for reducing them in this article set?

2. Data Collection and Sources

The data is collected from ScienceDirect (Elsevier) using tools of the integrated Scopus database. The articles were queried with a filter phrase 'lower truck emissions.' Only peer-reviewed research papers were selected. The search phrase was deliberately defined to be general and inclusive in order to gain a diversified sample of journal articles from different disciplines. The selection query was based on abstracts, not just keywords. One goal was to look at how this topic has been researched during the last 25 years: the first included article was published in 1995, after which the interest in researching emissions in freight transportation gained increasing popularity. In total, there were 161 papers found in the search. After the initial search, articles were grouped into content categories and their bibliographic information was used in content classification. Web of Science (WoS) impact factor (IF-index) was added to indicate how journals are ranked by citations.

The original 161 articles were further refined by using the keywords 'pollution' and 'emissions' in order to divide the large original set into a smaller and more clearly defined set. This procedure resulted in 21 articles for the detailed reviewing. The variety of listed keywords indicates that LDT and HDT emissions have been studied practically in all fields of science. This variety highlights the need for interdisciplinary research required in solving 'wicked' problems. The solutions evidently require analyses of disruptive environmental innovations, green investment strategies, non-voluntary legislation, and strategic global agreements.

Time-wise, the number of published articles has clearly increased after 2011. The trend has continued all the way until the final year 2019. This is reinforced by international regulation and legislation that have also experienced difficulties, e.g., in major international environmental summits in the commitment of major pollution producing countries. In addition, public awareness concerning discharges in traffic and transportation has increased, and the Intergovernmental Panel on Climate Change (IPCC) [11] report has stated that significant agreements should be reached quickly if the effects of climate change are to be limited to sustainable levels.

Table 1 indicates that, unsurprisingly, research articles (145) were the dominant form of papers. The most dedicated journal for the topic is Atmospheric Environment with 33 published research articles. As the journal title indicates, it focuses on all types of airborne emissions affecting the environment. Other significant journals focus on clean-tech in production, transportation studies, and general environmental issues.

Table 1. Article types and journal names. N refers to the number of studied articles in each venue.

Article Type (N)	Journal Name (N)
Review article (4)	Atmospheric Environment (33)
Research article (145)	Journal of Cleaner Production (16)
Book chapters (6)	Science of the Total Environment (14)
Conference abstracts (2)	Transportation Research Part D: Transport and Environment (12)
Short communications (4)	Applied Energy (9)
-	Energy (4)
-	Energy Procedia (4)
-	Energy Conversion Management (3)
-	International Journal of Hydrogen Energy (3)
-	Energy Policy (2)

Table 1 shows variety for a reasonable sample enabling the examination of how to achieve or take steps towards zero emission land transport. Similar research has been done earlier in the maritime context. For example, Hämäläinen and Inkinen [10] summarized that low emissions development will (or has to) cover several (clean) technology domains, starting from bio-fuels up to the physical transport routing optimization and waste water handling. In practice, this means that in hybrid ship designs there are no single solutions to convert an environmentally hazardous vessel into a responsible clean one. Also, pollution can be understood very widely, because especially trucks with diesel engines produce extensive amounts of various types of harmful emissions (e.g., PAH, CO2, NOx). Finally, scalability is significant as it refers to decreasing marginal costs where the increasing use of certain solution leads to decreasing costs.

3. Perspectives on Truck Freight Emissions and Pollution

The global efforts to accomplish zero emission logistics have been studied for several decades now. Changes are however slow, as Siskos and Moysoglou [12] remind us that the European Commission introduced, as late as 2018, CO_2 emission standards for truck manufacturers aimed at achieving reductions in air emissions caused by trucks. This is significant, as trucks are the second largest source of CO_2 emissions in the EU's road traffic.

There are numerous regional studies from around the world (e.g., from Latin America [13]; from Scandinavia [14]) indicating volumes of truck emissions in national contexts. Similarly, Shamayleh et al. [15] point out the significance of civic concerns and currently developing legislation on environmental issues. This results into the fact that enterprises should take up a more rigid view on responsibility. In discharge mitigation, a direct solution would be subsidization for clean-tech and bio-based fuels. However, the current availability of alternative fuel sources is still limited and it would be a challenge if demand increased significantly. There are also indirect impacts that bio-fuel production may entail, e.g., impacts on food markets and prices. For example, bio-gases, among others, are an alternative option for consideration. Additional solutions come from fiscal tools, e.g., [16].

Heavy taxation on transport would, however, also decrease total economic activity and thus lead into problems in all economic sectors.

In terms of engines, battery electric trucks (BETs) have been nominated as modern alternatives in the mitigation of the CO2 emissions of trucks [17]. There are several global examples of this, and Tanco et al. [13] carried out a study in Latin-America (Argentina, Brazil, Chile, Colombia, and Uruguay). They analyzed the main barriers for BET adoption. The initial investment requirement in particular is significant in total cost (current price difference favors diesel trucks) between the alternatives. Thus, the difference between the costs of electricity and fuel is highly important in achieving cost neutrality.

Handler et al. [18] analyzed the air emitted pollution from the forestry sector. Their empirical case focused on roundwood and was conducted in the USA (Michigan). The study fruitfully illustrates the needs of combining harvesting equipment adjustment and different operational scenarios in forestry. In addition, transport emissions are significant as majority of wood collection takes place in remote locations requiring specific truck types. Generic results prove that fuel types are essential in aiming to lower emission levels in freights, also as in [19].

Accordingly, Nanaki and Koroneos [20] noted that alternative fuel solutions (such as blended gasoline versions and biodiesels) have made a breakthrough on the fuel markets, for example, in the EU where fuel properties are strongly regulated. These considerations also remind that when using 'cleaner' fuels, they may have non-desired side effects even though they lower the worst pollution emissions. National differences are also significant as the study indicates. For example, Le and Leung [21] studied particle matter 2.5 volumes in Ho Chi Minh City (Vietnam). The measured particle levels indicate clear health risks as their measurements provide extensive coverage of the significant exceeding in particle concentrations in the air (measured for an hour per day out of the acceptable maximum). In these situations, spatial planning is one way to reduce engine emissions in densely populated areas.

Mitigating emissions is not only an engine technology or fuel matter. Traffic flow regulation and management provides a feasible platform for reducing emissions with responsible planning. These environmentally sound decisions may improve local air quality and diminish total emission volumes. Efficient regulation manifests itself e.g., in speed limitations. Panis et al. [22] point out the importance of simple speed limit regulation as they are the most common tools in improving road accident figures. For example, 30 kph zones have become commonplace in several EU countries. Slower maximum speeds also decrease air pollution—it is environmentally advisably due to the associated reduced fuel consumption leading to lower emissions. This is verified by a study where two different base speeds were used: normal private vehicles (small roads 30 to 50 kph) and trucks on motorways (80 to 90 kph). The results confirmed significant impact of speed in emission control and cost savings (fuel). The presented outcomes are examples of causalities relevant for decision making and implementing speed management policies.

4. Findings from the Articles

The selected 21 articles (19 of them with keywords, presented in Table 2) cover numerous aspects which could help in building zero emission freight transportation including both long and short delivery distances. These articles cover the years 1995–2019. The results are presented in Tables 2 and 3. They should be considered as a collective description of the articles. The selected articles are focusing on technology, fuel types, urban pollution, standards, fleet optimization (battery vs. diesel) and emission inventories, and electric vehicles.

Table 3 lists solutions and purposes of the studied articles. In order to support the classification, Appendix 1 presents a more detailed content list of the papers. In the case of single articles, the first one (number 1 in Table 3) analyzed how the continuous ethanol transportation by HDTs could be replaced by a pipeline where physical construction costs are extensive, but after the initial investments, pipelines do not produce as much HDTs emission and CO2 gases to the atmosphere.

Studies on regulation effects are widely present (e.g., numbers 2–8 in Table 3). In general, they have a unified message: more regulation results in lower emissions. This is verified with measurements before and after a specific environmental law or regulation comes to force. The papers include cases from around the world. For example, during the Beijing Olympic Games 2008 strict traffic regulations were put in force, which significantly improved local air quality. The time period is of the essence. Over short time periods (e.g., mega-events such as Olympics) quick improvements are achieved, but in the longer term, restrictions start to have a negative effect on economic performance. Thus, the balancing between legislative regulation and economic goals is evident.

Some collective interpretations may be drawn from Table 3. First, emissions control programs should include tools to remove high pollution emitters from the traffic or alternatively improve emission efficiency in existing vehicles. Wang et al. [23] remark that the median black carbon (BC) concentration after the control was significantly reduced, if compared to those days that were not under traffic control. Similarly, Wang et al. [24] studied black carbon through 'heavy emitters' (old diesel engine trucks) on the roads. Their study found out that the most polluting trucks caused often more than half of the total emissions (all particle matter) ranging from 41% up to 70%. Similar results were obtained also in the cases of other pollutants such as particle matter and carbon dioxides.

Table 2. Article keywords (19 out of 21, as two articles are without keywords).

2019 emission factors; euro VI hdvs; CO_2 emissions; NOx emissions; solid PN emissions
2019 fleet mix optimization; heavy-duty truck robust optimization; hybrid life cycle assessment; alternative fuel adoption; battery-electric heavy-duty truck; robust pareto optimal solutions
2019 urban air quality; ultrafine particles; active transport; mobile measurements; cycling infrastructure
2019 warehousing receiving process; detention fee; traffic congestion; environmental pollution; discrete-event simulation; truck check-in
2018 urban air pollution; mobile combustion sources; biofuels; emission policies; bus rapid transit
2016 externalities; transportation infrastructure; occupational safety; life-cycle assessment (LCA); economic input–output (EIO) analysis; greenhouse gas emissions
2016 vehicle; emissions; control; air pollution; China
2016 emission inventory; vehicular pollutants; COPERT model; the PYRD
2016 economic input–output-based hybrid LCA; electric delivery truck; multi-objective linear programming; conventional air pollution externalities
2013 externalities; freight transport; trends; fundamental factors; vehicle technology
2012 electric vehicles; economic replacement model; urban freight
2012 low emission zones; trucks; local traffic policies; traffic; air pollution
2012 emission factor; diesel; climate change; air pollution; nitrogen oxides; black carbon
2011 climate change; air quality; diesel; size distribution
2010 diesel particles; emission factor; composition; composite diesel PM2.5 profile; Bangkok
2009 olympics; air pollution; black carbon; climate change; health effects
2003 particulate-bound PAH; urban air pollution; Zaragoza; seasonal trend; emission sources
2003 fuel/propulsion system; greenhouse gas; global warming; life cycle analysis; life cycle assessment; alternative fuels
1995 exhaust emissions; motor vehicles; emission requirements; tax incentives; air pollution control

Table 3. First author, journal, year, impact factor (IF) index, title, and main purpose of the selected 21 papers. Texts in "main purpose" are direct quotes from the article descriptions.

Authors, Journal, Year, IF-Index, Title	Main Purpose
1 Strogen et al. (2016). Applied Energy. 7.9. Environmental. public health. and safety assessment of fuel pipelines and other freight transportation modes.	The construction of an ethanol pipeline from the Midwest to Northeast United States.
2 Wang et al. (2012). Atmospheric Environment. 4.012. On-road diesel vehicle emission factors for nitrogen oxides and black carbon in two Chinese cities.	Multi-pollutant control strategies and in-use compliance programs are imperative to reduce emissions from the transportation sector.
3 Wang et. al. (2009). Atmospheric Environment. 4.012. Evaluating the air quality impacts of the 2008 Beijing Olympic Games: On-road emission factors and black carbon profiles.	The emission control measures implemented to improve air quality during 2008.
4 Wang et. al. (2011). Atmospheric Environment. 4.012. On-road emission factor distributions of individual diesel vehicles in and around Beijing.	A field study of on-road emissions of diesel vehicles in and around Beijing, during November and December of 2009.
5 Grigoratos et al. (2019). Atmospheric Environment. 4.012. Real world emissions performance of h-d Euro VI diesel vehicles.	Real-world diesel Euro VI HDVs emissions of both gaseous pollutants and solid PN. For that reason, five HDVs, tested on-road under typical driving conditions.
6 Oanh et al. (2019). Atmospheric Environment. 4.012. Compositional characterization of PM2.5 emitted from in-use diesel vehicles.	PM2.5 emissions from diesel vehicles in Bangkok, providing Emission Factors appropriate for developing countries.
7 Wu et a. (2016) Environmental Pollution. 5.714. Assessment of vehicle emission programs in China during 1998–2013: Achievement. challenges and implications.	In China, vehicles are major sources of air pollution problems and it has adopted control measures to mitigate vehicle emissions. A local emission model (EMBEV) to assess China's first fifteen-year (1998–2013) efforts in controlling vehicle emissions.
8 Song et al. (2016). Journal of Cleaner Production. 6.395. Vehicular emission trends in the Pan-Yangtze River Delta in China between 1999 and 2013.	Emission factors from the COPERT IV model were used to determine emission inventories of CO, NMVOCs, NOx, BC, OC, PM2.5 and PM10 between 1999 and 2013.
9 Kuo et al. (2015). Journal of Transport & Health. 2.583. A06 San Pedro Bay Ports Clean Air Analysis.	Study analyzes the co-benefits of these policies on the reduction of greenhouse gases and regional pollutants, particularly as expressed through positive impacts on human health.
10 Feng et al. (2012). Procedia - Social and Behavioral Sciences. 0.78. Conventional vs Electric Commercial Vehicle Fleets: A Case Study of Economic and Technological Factors Affecting the Competitiveness of Electric Commercial Vehicles in the USA.	Competitiveness of commercial electric vehicles and trucks have the potential to substantially reduce greenhouse gas emissions and pollution and lower per-mile operating and maintenance costs.
11 Pérez-Martínez & Vassallo-Magro (2013). Research in Transportation Economics. 1.798. Changes in the external costs of freight surface transport In Spain.	Analyses the external costs of surface freight transport in Spain and finds that a reduction occurred over the past15 years.
12 MacLean & Lave (2003). Progress in Energy and Combustion Science. 26.467. Evaluating automobile fuel/propulsion system technologies.	Fuel emissions technologies, customers require rethinking of regulations, design of vehicles and appeal to consumers over the next decades. Vehicles more than 35mpg make up less than 1% of new car sales.
13 Sen et al. (2019). Resources. Conservation and Recycling. 7.044. Robust Pareto optimal approach to sustainable heavy-duty truck fleet composition.	Sustainable trucking, objectives are considered, minimizing the life-cycle costs (LCCs), life-cycle GHGs (LCGHGs), and life-cycle air pollution externality costs (LCAPECs).
14 Boogaard et al. (2012). Science of The Total Environment. 5.589. Impact of low emission zones and local traffic policies on ambient air pollution concentrations.	Air pollution at street level before and after low emission zones (LEZ) directed at heavy-duty vehicles (trucks) in five Dutch cities in different background locations 2008 and 2010.
15 Olsson (1994). Science of The Total Environment. 5.589. Motor vehicle air pollution control in Sweden.	Light-duty and heavy-duty trucks and buses also need to be certified against stringent emission requirements. The equipment's ability to meet the use requirements.
16 Mastral et al. (2003). Science of The Total Environment. 5.589. Spatial and temporal PAH concentrations in Zaragoza. Spain.	The concentration of polycyclic aromatic hydrocarbons (PAH) was measured in the Zaragoza (North-East of Spain) atmosphere using fluorescence spectroscopy in the synchronous mode (FS).
17 Smith & Srinivas (2019). Simulation Modelling Practice and Theory. 2.426. A simulation-based evaluation of warehouse check-in strategies for improving inbound logistics operations.	Minimize the detention fees paid to the carrier by enhancing the check-in process of the inbound trucks, with the secondary goal of reducing the CO^2 emissions.
18 Walsh (1998). Studies in Surface Science and Catalysis. 1998 Global trends in motor vehicle pollution control: a 1997 update.	Air pollution is a common phenomenon necessitating aggressive motor vehicle pollution control efforts. Survey of what is presently known about transportation related air pollution problems.
19 Zhao et al. (2016). Sustainable Production and Consumption. 1.4. Life cycle based multi-criteria optimization for optimal allocation of commercial delivery truck fleet in the United States.	Alternative fuel trucks may mitigate environmental impacts. Cost of these el trucks is higher than those of diesel. Environmental, social, economic indicators are studied, a model provides solutions for a fleet of 30 commercial delivery trucks.
20 Le & Leung (2018). The Lancet Planetary Health. 2.736. Associations between urban road-traffic emissions. health risks. and socioeconomic status in Ho Chi Minh City. Vietnam: a cross-sectional study.	The public health associated with urban road-traffic emission in HCMC, and whether reducing air pollution will decrease hospital admissions, premature deaths, and years of life lost. The association between air pollution and socioeconomic status.
21 Policarpo et al. (2018). Transportation Research Part D: Transport and Environment. 2.34. Road vehicle emission inventory of a Brazilian metropolitan area and insights for other emerging economies.	Vehicle emissions of carbon monoxide (CO), non-methane hydrocarbons (NMHC), aldehydes (RCHO), nitrogen oxides (NOx), and particulate matter (PM) in a metropolitan area using a bottom-up method, between 2010 and 2015.

One solution is to develop engine technology. For example, investments in environmentally efficient fleet are a solid method for diminishing pollution from freights. Different regulative standards play a role here. For example, EU standardization levels II, III, and IV in buses are significantly different in terms of pollutant tolerance. This is exceedingly important in densely populated areas (e.g., large Chinese cities, see [25]). It is considered that, particularly in economically growing developing countries, instead of acquiring older diesel engine HDTs there should be a direct leap into clean-tech transport vehicles and low polluting engines following the strictest standards.

Policarpo et al. [26] studied the road emissions and fleet properties in Brazil. The number of vehicles in their study area of Ceará has grown significantly, almost doubled since 2008. They estimated trends from various harmful emission types caused by the road traffic in 2010–2015 with a macro-simulation. Their results showed that the implementation of environmental regulation and policies are efficient means to decrease emissions. They cause and motivate an accelerated phase in the adoption of clean-tech in transport business. Alternatively, an optimization model, designed by Zhao et al. [27], considers tailpipe emission constraints focusing on combustion emission after treatment. Their study indicated that the environmental performance may be categorized into three main impacts (classes of economy, environment, and health). They made a distinction to dichotomous categories and gave recommendations for selecting different engine types according to economic conditions. The end results clearly indicated that hybrid solutions should be preferred when transport demand (high utilization) is in progress. Diesel engines are viable options in the non-probable scenario where the oil economy is booming and transport demand is low.

In China, and generally in Asia, combustion engine vehicles are the major source of harmful emissions and therefore the mitigation of vehicle emissions are paramount. Oanh et al. [28] point out that especially particle matter (PM) EF levels are lower for new vehicles, indicating consistent development with progression in engine technologies and low emission engine standards. Accordingly, electronic vehicles are an interesting venue for research. However, they were studied the first time in 2012 among the selected 21 papers. In the broader original 161 paper data set, the first paper on electric vehicles was published in 2003. However, this topic is still considered 'experimental' as the maturity level of electronic trucking is still very low. They will remain a marginal means of transport in professional use in the decade-long time-span until 2030.

Walsh et al. [29] stated more than 20 years ago that four trends are the most important in road traffic market development, including clean-tech and emission control:

1. Global population growth;
2. Increasing wealth of countries with lesser development increases global traffic volume;
3. Cleaner environment results into healthier population;
4. Governmental responses and regulations. Continuous restrictions on newly produced model emissions levels.

In order to conclude, it is worthy to remember that China produced approximately double the global greenhouse gas (GHG) emissions in comparison to that of the second largest polluter (US) and three times that of the European Union [30]. The annual growth rate is also the highest in China. The total number of motorized vehicles also soon exceeds 700 million globally. Out of that number, approximately half a billion are small cars, and approximately 150 million are trucks and buses. The rest are motorcycles. The growth rates are also significant. Vehicle growth rates have slowed down in economically advanced countries where natural population growth is slow. The main growth areas for vehicles are in developing countries that are experiencing high economic growth together with increasing urbanization.

5. Summary and Conclusions

The summarizing results of this review are presented in Table 4. There are some overlapping topics in these categories, but it is considered that the table provides the best interpretive view of the data. The studied articles exposed several environmentally friendly solutions, which are reasonable and executable in the near future. However, some of the solutions might be easier and faster to implement while some need slower incremental implementation. The summary is presented according to these categories:

1. Fuels and engine innovations;
2. Other innovations and methods to lower emissions;
3. Infrastructure: Route, spatial planning, controls.

Table 4. Summary of the methods to lower and mitigate emissions in HDT transport.

1. Fuels and Engine Innovations	2. Other Innovations and Methods to Lower Emissions	3. Infrastructure: Route, Spatial Planning, Control
HDTs motor innovations: - Electric motor - Battery capacity, route planning - City deliveries	**HDTs and LDTs in fleet optimization:** - Valuable things, combination of electric and HDTs and LDTs depending of routes and places in use - Replacing whole or part of the fleet - Capacity, routes	**HDTs and traffic control:** - Emission control measures implemented to improve air quality, - HDTs can be responsible for 50% of total BC emissions, and 20% of trucks are responsible for 50% CO_2, PAH emissions control - Reducing black carbon
HDTs with new fuels solutions: - Fuel emissions technologies, flex fuel vehicles, noticeable reduction in NOx and PM emissions, emission standards - LNG-trucks, Methanol, Biofuels, Hydrogen	**HDTs replaced with other innovations:** - Pipelines, electric rails, electric ships	**HDTs and traffic planning:** - Shifting freight deliveries from peak to off-peak hours, lower local emissions
HDTs and exhaust gas types and treatment: - Large and growing vehicle pollution control market, especially with regard to exhaust after treatment systems. - Try to reveal exhaust gas types.	**Vehicle buyers, customers, consumer behavior is changing:** - Consumers now demand larger, more powerful personal vehicles, ignoring fuel economy and emissions of pollutants. - Legislation, tax-policy	**HDTs and spatial planning:** - Reducing motor emissions from motorcycles, trucks, and buses, produce health benefits based on better land-use and transport planning, - Low emission zones for urban road-traffic emissions

HDTs, heavy-duty trucks; LDTs, light-duty trucks; PAH, polycyclic aromatic hydrocarbons.

The articles verify that in traditional truck and freight transportation, the environmental focus has not been in airborne emissions and mitigation. There are also different opinions in the research regarding the urgency of the matter: Some articles stated that the transportation industry in developing countries should be allowed to use old trucks that are producing larger amounts of airborne emissions until their gross national products are comparable to developed countries. The economic growth would allow increasing investments in more sustainable vehicles. Generally, this view is considered invalid, e.g., by the IPCC. The best solution would be that all countries should have similar standards and global regulative directives should be used as is the case in the maritime sector following International Maritime Organization (IMO) regulations.

In the leftmost column (number 1) of Table 4, solutions are presented that require extensive and significant changes to current fleets. They address technological engine innovations and solutions such as renewable bio-fuels. They would impact the emission volume greatly but their costs are still exceedingly high and the maturity of these technologies young. However, their use would create a direct and clear change towards low (and even zero) emission goals in LDT and HDT freight transports. The most important management actions and key changes in order to implement these technological advancements include taxation legislation (regulation), after sales support systems and continuous product enhancement system based on the operational performance (malfunctions, fatigue, battery duration) indicators and feedback. An alternative in some geographical locations would also be to replace HDTs with other cleaner means of transport (e.g., direct pipelines, railways, or short sea shipping). However, these solutions are highly dependent on the existing infrastructure and land-water area properties. It will remain the responsibility of LDTs to manage the final short delivery distances. Therefore, innovative truck development will continue to be an essential part of emission reduction and control.

There is also a chance to mitigate emissions by using company-level optimization in daily operations. For example, on long and midrange routes biodiesel trucks should be preferred, and light-duty battery trucks (LDBT) are preferable instead for very short distance transports in urban environments. This type of fleet building is already a reality in economically advanced countries. However, fleet building takes time and therefore regulative exhaust limitations are needed to accelerate the process. A quicker and cheaper solution for the near future would the continuation of the use of existing HDTs and LDTs. They could be converted to use biodiesel, methanol, or liquefied natural gas (LNG). This would gradually replace old diesel trucks with zero or low emissions ones.

In the middle column (number 2), the final row addresses the role of truck markets, buyers, and end customers. The market-driven change towards cleaner freight transportation would be easier if all customers of transport companies would require only clean truck deliveries for their products. However, this not yet possible (on a large scale) and a reason for this is that prices are too high. A second simple reason is the limited availability of low emission trucks. In the case of an absolute need to mitigate emissions (e.g., in inner city deliveries), the best way would be to use electric (battery driven) HDTs. An alternative solution is to restrict the amount of traffic as has been done e.g., in Beijing and other megacities suffering from low air quality. One fuel-related solution is to use more than one fuel tank in trucks. In this case a truck may switch between different fuel types in accordance to local emission restrictions. A challenge is that the fuel types store energy with different capacities. This has a direct impact on the transportation distances. Diesel has the highest storage capability whereas hydrogen and electricity have the lowest energy storage characteristics.

In larger countries with long transport distances, diesel HDTs are now the most used vehicles in freights and this will remain so for several years into the future. In these countries, modal change could be made (in some scale) in order to use trains as feeders, for example in container deliveries, and final connections could be organized by diesel (to some extend even refined from renewable materials) or gradually in the future by battery-driven trucks. In this modal transition a common challenge is that train network connections cover only limited areas. Railway building is an expensive investment and is viable only in locations with enough transport volume now and especially in the long run. This is one of the main challenges in nationwide transport planning in several countries that experience unbalanced population concentrations (e.g., sparsely populated Nordic countries).

The rightmost (number 3) column presents solutions focusing on infrastructure. These include issues related to route and spatial planning, control technology, and emission measurement. The articles address the fact that pollution levels are lower in locations where regulations and restrictions have been established. Improvement of measurement is crucial action and the related studies among this third category papers indicate that HDTs may produce more than half of total BC emissions. There has also been continuing research in which different time intervals have been applied in order to tackle temporal change in air quality. In addition, the case locations are places where air quality is low or very low to begin with. It is evident that direct measurement studies are the best way to indicate emission levels and air quality. They should also be in the best position to be applied in emission regulation decision making. The final main action should be the recognition and understanding that road and spatial planning have the best potential to aid emission problems by distributing the HDT traffic during peak hours, particularly in cities. These efforts do not necessarily lower the overall emission amount, but distributing it to broader time-spans helps with the most severe pollution peaks.

The production of electric vehicles has an impact on environmental pollution mainly for two reasons that were restricted outside our paper: First, it is not well known what the environmental impact is on the production means and disposal of newly emerged energy sources, especially batteries. This is an important study subject for the future. Second, the production of energy that is used to charge and power electric vehicles comes mainly from the combustion of coal, which is of great importance, especially in countries and regions where this energy is generated. Therefore, it should be taken into account in the final assessments of the impact of car transport on environmental pollution. An additional future research task emerges from the development potential of hydrogen trucks and the use of digital applications, enabling e.g., "truck sharing," thus developments taken place already in the use of private cars.

To conclude, these specifically targeted 21 peer-reviewed research papers provided a large variety of approaches, measurements, and case studies from all around the world. The papers proved the diversity of options and obstacles in the pursuit for low- or zero-level emissions in freight transport. These findings are focusing on impact that the diverse set of actions may have in relation to emissions levels. Understandably, the goal of reaching zero-level emission levels is realistically challenging to achieve, perhaps just only lower if the whole manufacturing, maintenance, and other indirect processes are considered. For example, the manufacturing of batteries for electric vehicles requires significant amounts of valuable metals, of which some are rare. Mining processes, refining and transportation of (raw) materials to battery manufacturing and assembling sites require energy and thus produce emissions. Therefore, in actual road transportation business, all possible operations should be reconsidered from the viewpoint of engine and fuel technologies, which should produce clearly lower emission levels (i.e., green innovative disruptions). If these are not achieved, then modal changes from roads to train and maritime transportation could bring benefits in long time span with some logistics limitations such as how to reach markets outside train and ports. This study clearly addresses that re-designing future clean freight transport based on trucks system needs to be done in a broad way to include the latest fuel and engine technologies (and related solutions), parallel to driving road logistic towards the lowest possible emission levels and mitigation of harmful substances. This could be concluded as the only answer to reach an improved environmental situation bringing positive impacts on human health. At the same time, it is important to remember that freight transportation on roads is expected to increase globally in the coming decades.

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