Freight Transport in a Low-Carbon World

Assessing Opportunities for Cutting Emissions

ALAN McKINNON

The author is Professor of Logistics, Kuehne Logistics University, Hamburg, Germany.

The freight transport sector faces a daunting climate change challenge in the next few decades. Several recent studies have quantified the scale of this challenge against the baseline assumption that the increase in average global temperature from 1850 to 2100 must be less than 2°C. The COP21[1] agreement in Paris endorsed this environmental objective in December 2015, stipulating that the temperature rise should be "well below" 2°C.

According to the Intergovernmental Panel on Climate Change (IPCC), the United Nations body responsible for analyzing scientific evidence on the subject, annual greenhouse gas (GHG) emissions through 2050 must not exceed 20 billion tonnes of carbon dioxide equivalents (CO_{2e}) for a 50 percent or higher chance of staying within the 2°C limit (*1*). The IPCC also predicts that transport emissions on a business-as-usual basis could reach 12 billion tonnes of CO_{2e} by 2050 (*2*)—that is, transport would generate a 60 percent share of all permissible emissions.

For transport to remain at its current share, its total GHG emissions—6.5 billion tonnes of CO_{2e} in 2010—would have to drop to 3 billion tonnes over the next 34 years. This presents a formidable challenge for planning and managing transport systems. The task will be even harder for freight transport, because its share of total transport emissions is expected to rise from 42 percent in 2010 to 60

[1] 21st Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change, the United Nations body responsible for climate-related policies; based in Bonn, Germany.

A traffic jam in rural Qinghai, China. As freight transport grows, particularly in China or India, so does the challenge of reducing global greenhouse gas emissions from transportation.

PHOTO: TIM ZACHERNUK, FLICKR

Photo: Frans Berkelaar, Flickr

Container cranes at the Port of Rotterdam in the Netherlands. The European Union set a target to cut transportation-based carbon emissions by 60 percent between 1990 and 2050; in approximately the same time period, freight transportation is expected to increase by 57 percent.

percent by 2050 (*3*). Freight transport has been identified as one of the hardest socioeconomic activities to decarbonize (*4*).

Carbon Intensity

Against this background, governments and companies are trying to cut the carbon intensity of freight transport operations, although many appear to underestimate the magnitude of the reductions that will be required. Moreover, corporations invariably express the carbon reduction targets for logistics in terms of carbon intensity, such as grams of CO_{2e} per tonne-kilometer, but governments express their objectives for deep cuts in terms of the total amount of GHG emitted. Nevertheless, meeting these objectives could be almost impossible if current forecasts of the growth in freight movement become reality.

The European Union (EU) offers an illustrative example. In 2011, the European Commission set a target to cut total CO_2 emissions from passenger and freight transport for the 27 EU countries by 60 percent between 1990 and 2050 (*5*). Making allowance for growth in tonne-kilometers between 1990 and 2010 and the projected increase of 57 percent in freight transport between 2010 and 2050, the carbon intensity of freight movement would have to plunge to approximately one-fifth of its 1990 level to meet the target (*6*).

Freight Projections

In other parts of the world, the projected growth in freight movement is much higher, pressing governments and businesses to find ways to decrease GHG emissions per tonne-kilometer. For example, the International Transport Forum (ITF) expects the rate of increase in total tonne-kilometers between 2010 and 2050 to be three times higher in China and India than in the EU and North America.

Current projections may exaggerate the future growth of freight traffic worldwide. Some assume that the volume of international trade will grow several times faster than the global gross domestic product (GDP), because between 1950 and 2008 trade increased three times faster than GDP (*7*). But these growth rates have converged since 2008, suggesting that in the longer term the trade–GDP elasticity may be closer to one to one.

The so-called reshoring of manufacturing activity from emerging markets back to developed countries, the relocalization of food supply chains, and the contraction in international flows of fossil fuels could decouple the growth of trade negatively from that of global GDP (*8*). The miniaturization, digitization, and 3-D printing of products could dematerialize some of the flows, depressing the demand for freight transport between and within countries.

Collectively, these developments could reduce significantly the freight transport intensity of the global economy, although this appears improbable. Several other factors are likely to counteract. Implementation of the 2013 Bali Accord to facilitate trade, along with regional trade agreements, may expand trade volumes; moreover, the decline in oil prices has depressed the real cost of international transport. Predicting the net effect of these trends on freight traffic is difficult.

Whatever the net business-as-usual trend, it is doubtful that governments will try to dampen the

PHOTO: ROGER, FLICKR

A vintage truck delivers goods to Portland, Oregon, from a small farm nearby. Because transportation is a relatively small part of a product's carbon footprint, localized sourcing for food and other products does not always lead to fewer GHG emissions.

demand for freight transport to mitigate climate change. Despite mounting concern about global warming, political commitment to economic development remains paramount, and the unfettered movement of goods is considered intrinsic to this process.

Minimizing Emissions

Forcing a return to more localized sourcing would not necessarily yield large carbon savings. Many life-cycle analyses have demonstrated that production activities account for a much larger proportion of the average product's carbon footprint than transport (*9*). Therefore, making or growing products in locations in which the production-related emissions are low is preferable, even if this entails long distances to markets.

Minimizing emissions from freight transport may not minimize the total life-cycle emissions of the products. Governments and international organizations need to recognize this in setting carbon-reduction targets for the freight sector.

The decarbonization of other sectors also will inflate future demand for freight transport. For example, switching energy-generating capacity from fossil fuels to renewable fuels and nuclear power will require the movement of vast amounts of material over long distances. The supply chains for wind turbines, solar panels, and batteries span the globe. Once the new low-carbon energy infrastructure is in place, the movement of fossil fuels will largely disappear, but the changeover may take several decades.

Climate Change Adaptation

The transport sector will also carry much of the burden of climate change adaptation. Adaptation may prove to be as great a preoccupation as mitigation among transport planners, managers, and policy makers. Current concern is for the climate-proofing of transport infrastructure to withstand more extreme weather events and sea-level rise.[2]

Adaptation, however, raises wider issues, including the nature and scale of the material flows required to strengthen and realign infrastructure, build up coastal protection, and relocate vulnerable settlements. These are freight-intensive activities. Few long-term freight forecasts at the national or global levels allow for the effects of climate change adaptation on traffic volumes. Ironically, the movement of materials to protect the built environment against climate change will increase freight transport emissions, conflicting with mitigation initiatives in the logistics sector.

Decarbonization Parameters

In summary, although future growth in demand for freight transport may not be as explosive as some studies suggest, the growth is likely to be robust and largely justified on the grounds of economic development, cross-sectoral decarbonization, and the climate-proofing of settlements and infrastructure. If reducing total tonne-kilometers proves almost impossible, decarbonization efforts will have to focus on driving down the average carbon intensity of freight transport to a fraction of the current level.

Fossil fuels have a robust energy infrastructure in North America, but as the infrastructure for low-carbon energy sources develops, the demand for fossil fuels will fall.

PHOTO: CAN PAC SWIRE, FLICKR

[2] The Transportation Research Board, the U.S. Department of Transportation, and the European Commission conducted a symposium on this topic in Brussels in June 2016 to promote trans-Atlantic research collaboration. See Conference Proceedings 53, *Transportation Resilience: Adaptation to Climate Change and Extreme Weather Events*, www.trb.org/Main/Blurbs/175488.aspx.

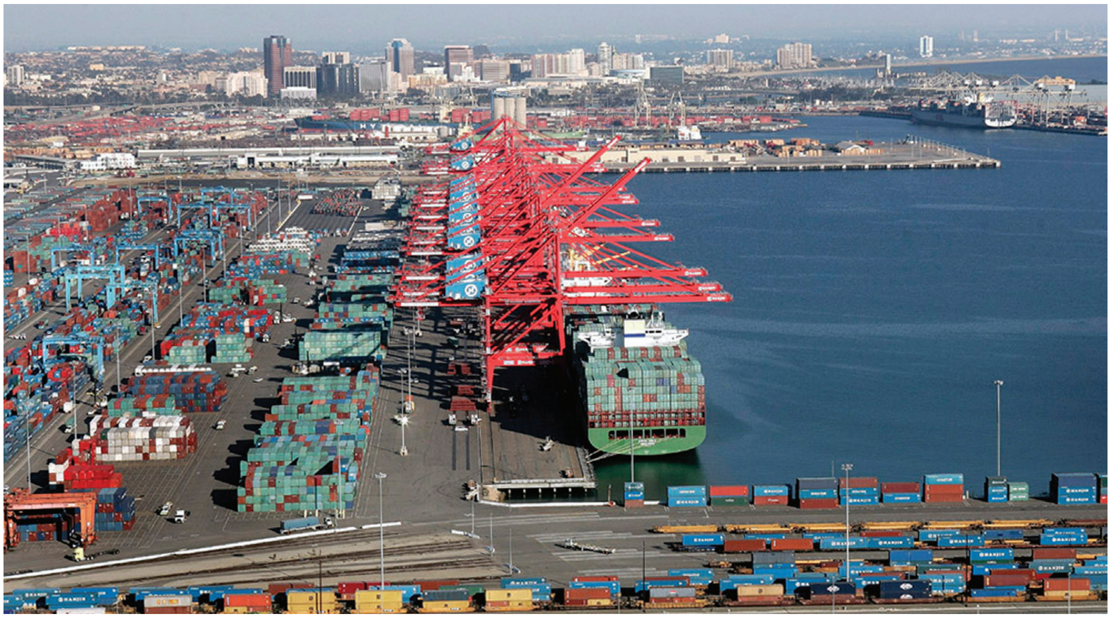

Photo: Port of Long Beach

Multimodal freight activity at the Port of Long Beach, California. Carbon emissions in the growing freight sector can be reduced through initiatives in five main areas: supply chain structure, modal split, vehicle utilization, energy efficiency, and energy mix.

Carbon emissions per tonne-kilometer can be reduced in many mutually supportive ways that can be classified with respect to five parameters: supply chain structure, modal split, vehicle utilization, energy efficiency, and energy mix.

Supply Chain Structure

The supply chain structure determines the amount of freight movement generated per unit of output. Cutting the number or length of links in the chain can reduce the tonne-kilometers for a given amount of output. The vertical integration of manufacturing processes and the disintermediation of distribution channels—for example, the bypassing of wholesalers—removes links from the chain, and localized sourcing shortens the average length of haul.

When economies develop, distribution channels tend to become more direct, as multiple retailers—that is, chain stores—expand their logistical capabilities and receive supplies in bulk from producers. This trend generally has been beneficial in reducing carbon emissions. In recent decades, however, many manufacturing processes have spatially fragmented, adding value at many different locations. Meanwhile, procurement has become more geographically extensive, and supply lines have steadily lengthened. These trends have generally increased carbon intensity. Reversal will require a fundamental change in business practice.

The centralization of inventory in fewer, larger distribution centers is another structural trend that is usually portrayed as increasing the carbon intensity of logistics. In the past 20 years in Europe, within the single market, companies have moved from nationally based to pan-European logistics, often supplying the whole continent from one or two distribution centers.

In a low-carbon world, companies may have to return to more decentralized warehousing. Although this would reduce transport-related emissions, warehousing emissions per unit of throughput would likely rise, and the resulting increase in inventory levels would probably carry a carbon penalty.

A full carbon trade-off analysis is needed, therefore, to determine the net change in emissions for the logistics operation as a whole. Because transport's share of a company's carbon footprint from logistics is typically 8 to 9 times greater than that from warehousing, analysis normally reveals a net savings in emissions; nevertheless, high capital and inventory costs make warehouse decentralization a relatively costly mitigation measure.

FIGURE 1 Average carbon intensity of freight transport modes. (Source: IPCC, 2014.)

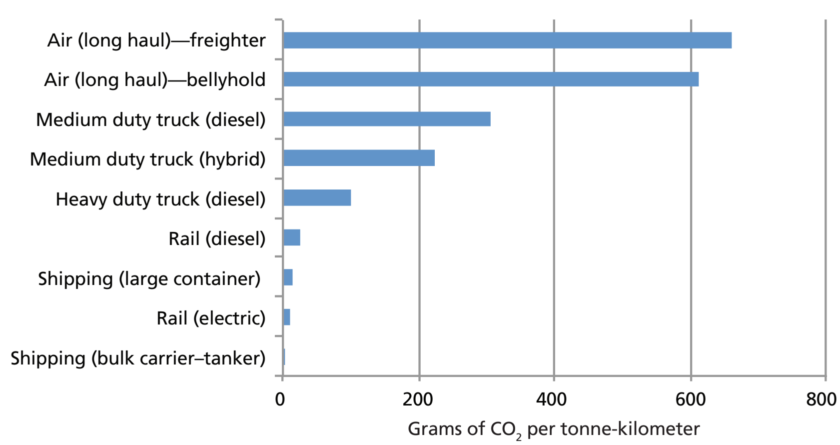

Photo: JPC24M, Flickr

Rail cars near Nièvre, France. Rail's share of freight in some countries, such as France and India, has declined.

Freight Modal Shift

The average carbon intensity of freight transport modes varies enormously (Figure 1, page 11). Shifting freight to modes with lower intensities is considered one of the most effective ways to decarbonize logistics, but the potential for modal shift varies from country to country. The tactic often involves reversing a long-term erosion of rail and waterborne freight tonnage.

In countries such as France and India, the market share for rail has declined significantly; in contrast, Mexico and the United Kingdom have reversed the contraction, largely through liberalization and privatization programs. In Germany and the United States, rail's share of freight has remained relatively stable (*10, 11*).

The European Commission has set an ambitious target of having 30 percent of freight tonnage traveling 300 km or more move by rail or water by 2030 (*5*). The capacity of European rail infrastructure will have to increase to handle the growth in rail tonne-kilometers, along with the accompanying growth in rail passenger volumes. Infrastructure expansion makes this a relatively expensive option for carbon mitigation—and carries a significant carbon penalty.

Comparisons of the GHG impact of the freight modes are largely confined to direct vehicle emissions. Extending the carbon calculation to include the construction and maintenance of infrastructure alters the relative carbon intensity of the modes, but detailed research is needed to determine the net effects.

Vehicle Utilization

Capacity

All freight transport modes underutilize carrying capacity. Improving utilization cuts the number of vehicle-kilometers required to move a given amount of freight and would yield energy and CO_2 savings. Efforts to raise vehicle load factors are usually self-financing, making this one of the most cost-effective ways of cutting carbon emissions.

Nevertheless, quantifying the underused capacity is difficult, because most countries—including the United States—lack macrolevel statistics (*12*). EU data suggest that in 2010, 27 percent of truck-kilometers were empty, and the average weight of consignments on loaded trips reached only 57 percent of the maximum (*13*). This can be misleading, however, because many consignments of low-density products can fill the available space before reaching the weight limit.

Without volumetric data, assessing the potential for improving truck utilization is not possible. On container ships, the average utilization of slots was estimated to be 74 percent in 2013 (*14*), and the International Air Transport Association has reported that air freighters use only 45 percent of "available freight tonne capacity" (*15*).

Table 1 (left) lists the main constraints on the loading of freight vehicles. Some are difficult to overcome, such as geographical imbalances in traffic flow. Others can be eased by changes in business practice, regulation, and technical standards, as well as by effective use of information technology.

TABLE 1 Factors Constraining the Loading of Freight Vehicles

Factor	Effect
Market	Demand fluctuations
	Uncertainty about transport requirements
	Limited storage capacity at destinations
	Geographical imbalances in traffic flow
	Limited use of online load matching
Business practice	Just-in-time replenishment
	Poor coordination of purchasing, sales, and logistics
	Lack of supply chain visibility
	Reluctance to join collaborative load-sharing schemes
Regulation	Vehicle size and weight restrictions
	Health and safety rules
	Cabotage restrictions
Equipment	Nature of packaging and handling equipment
	Incompatibility of vehicles and products for backloading
Infrastructure	Unreliable delivery schedules
	Lack of load consolidation facilities

Business Efficiencies

Among business practices, just-in-time (JIT) replenishment is frequently blamed for sacrificing transport efficiency to minimize inventory. Some environmentalists argue that JIT has no place in a low-carbon world. JIT, however, is not simply a stock control system but a business philosophy that cuts waste and raises productivity across production and distribution processes. Although JIT may raise the carbon intensity of delivery operations, the carbon efficiency gains within factories, warehouses, and shops may offset the additional emissions.

Logistical collaboration between companies is another business development that offers carbon benefits—companies sharing vehicle and warehouse capacity to improve utilization of these assets. Usually motivated by cost cutting, the practice can yield impressive environmental benefits. For example, by a process of "collaborative synchronization," Nestle and Pepsico were able to cut CO_2 emissions per tonne of product delivered in Benelux[3] by 26 percent compared with a conventional groupage by a logistical service provider and by 54 percent compared with each company separately managing the logistics from in-house (*16*).

Truck Size and Weight

In the regulatory arena, relaxing restrictions on truck size and weight can yield a net carbon benefit, even after allowance for effects such as a modal shift from greener modes or the generation of new traffic. Experience in countries such as Sweden, Finland, Australia, Canada, South Africa, and Mexico, and in some states, confirms that high-capacity vehicles (HCVs), with lengths exceeding 20 meters and maximum gross weights above 45 tonnes, can cut carbon emissions per tonne-kilometer (*17*).

HCVs also offer many cobenefits by lowering labor requirements, vehicle-kilometers, accident levels, and pollutant emissions. Offsetting these benefits are the economic and environmental costs of the infrastructure modifications to accommodate the vehicles.

Raising limits on truck carrying capacity is undoubtedly one of the most controversial ways of decarbonizing the freight sector. Debates on the subject have been intense on both sides of the Atlantic. In the longer term, however, HCVs are likely to play an important role in the deep decarbonization of the trucking sector.

Energy Efficiency

Technologies

The energy efficiency of all freight transport modes has improved dramatically, mainly through advances in vehicle technology. Energy efficiency—expressed as energy consumed per vehicle-kilometer—can be pushed to higher levels. The U.S. supertruck project, for example, has shown that multiple technologies,

[3] Belgium, the Netherlands, and Luxembourg.

PHOTO: OAK RIDGE NATIONAL LABORATORY

A Cummins–Peterbilt SuperTruck uses advanced technologies to increase fuel efficiency.

Photo: Slawos, Wikimedia Commons

The Maersk Triple E class container ship—a class named for the design principles of economy of scale, energy efficiency, and environmental improvement—incorporates the "slow steaming" strategy, which can lower fuel consumption by more than one-third.

including turbocharging, hybridization, aerodynamic profiling, and lightweighting,[4] can raise the mileage per gallon by as much as 115 percent (*18*).

The challenge is to encourage commercial application of these fuel-saving technologies. In Europe, particularly in the United Kingdom, high fuel taxes provide a strong incentive for companies to design, make, sell, buy, and run more fuel-efficient trucks.[5] Japan, China, and the United States have introduced fuel economy standards for new trucks. The U.S. policy is expected to yield fuel and CO_2 savings of 30 to 45 percent for new articulated trucks between 2010 and 2027 (*19*).

The maritime sector has adopted a similar approach. The International Maritime Organization (IMO) now requires all new vessels to have an Energy Efficiency Design Index based on energy use and CO_2 emissions per capacity-kilometer and is steadily raising the minimum acceptable index. This measure could save approximately 260 million tonnes of CO_2 by 2030 and in combination with another energy efficiency initiative for operating vessels, could improve the fuel efficiency of shipping as a whole by 40 to 60 percent between 2012 and 2050 (*20*). The long life span of ships—and of aircraft and locomotives—constrains the rate at which the average fuel efficiency can be raised, although all three modes can benefit in the short-to-medium term from the retrofitting of fuel-saving devices.

[4] Turbocharging involves pumping more air into an engine's combustion chamber to improve thermal efficiency; hybridization propels a vehicle by more than one source of power, typically combining an internal combustion engine with battery power; aerodynamic profiling streamlines a vehicle to reduce wind resistance and improve fuel efficiency; lightweighting reduces the empty weight of the vehicle to increase carrying capacity and improve fuel efficiency.

[5] In November 2016, diesel fuel was 2.3 times as expensive in the United Kingdom as it is in the United States.

Operational Changes

Some of the largest energy-efficiency gains in the freight sector have come from operational changes. For example, the "slow steaming" of ships—operating at less than design speed—was introduced in 2007, when prices for bunker fuel[6] were high and volumes of trade were plummeting; IMO estimates that the practice cut average daily fuel consumption by 27 percent between 2007 and 2012 (*20*). The latest generation of container ships is designed to sail at slower speeds, effectively embedding this carbon-reducing practice into maritime operations.

Many large U.S. road carriers have voluntarily installed speed governors in their trucks and have set maximum speeds significantly below legal limits, primarily to save fuel. The deceleration of freight services may become more widespread across the logistics sector as a measure for decarbonization, reversing the traditional pursuit of ever-faster delivery (*21*).

Energy Mix

The repowering of logistics operations with low-carbon energy is at an early stage. In most countries, the carbon content of grid electricity is still relatively high; as a result, electrifying freight operations confers minimal carbon benefit. Decarbonizing the generation of electricity will strengthen the environmental case for vehicle electrification.

Countries with electrified rail networks and extensive battery recharging infrastructures for local delivery vehicles will then be able to achieve deep cuts in freight-related emissions. The electrification of highway lanes with overhead cables and hybrid diesel–electric trolley trucks, undergoing trial on a track in Germany, may prove a cost-effective way to decarbonize long-haul trucking.

The use of low-carbon fuels is likely a more economical route to decarbonizing long-distance road freight. Low-carbon fuels are the main alternative energy option for ships, aircraft, and freight trains operating on nonelectrified networks. The freight sector makes limited use of fossil-based, low-carbon fuels, such as compressed or liquefied natural gas, or of biofuels.

The main use of biofuels is in the trucking industry. In Europe, for example, the percentage of biodiesel blended with conventional diesel fuel has risen in response to EU and national government mandates, but only to approximately 5 percent in 2013 (*22*). Although many truck and engine manufacturers now approve the use of higher-percentage biodiesel blends, interest in switching to biodiesel

[6] Bunker fuel is the heavy, dense oil used in the maritime sector; also known as heavy fuel oil.

has waned because of uncertainty about the life-cycle GHG impacts and the effects on food supplies and land use.

Biogas made from food and agricultural waste has one of the lowest life-cycle GHG emissions and land use impacts, but the supply is limited in many countries, the refueling infrastructure is sparse, the costs per unit of energy are relatively high, and the freight sector is not likely to be a priority user. In the maritime sector, IMO envisions a relatively slow switch from conventional bunker fuel to liquefied natural gas, possibly reaching one-quarter of all fuel used by 2050 (*20*).

Toward Low-Carbon Logistics

Freight transport's share of 7 to 8 percent of global GHG emissions could rise substantially in the next few decades, if the forecasts for freight traffic materialize and little is done to cut its average carbon intensity. At a global level, the traditional relationships between freight volumes, trade, and GDP may weaken, but climate change mitigation and adaptation efforts may impose new demands on the freight sector, making absolute reductions in its total emissions more difficult.

Diverse and mutually-reinforcing opportunities are emerging, however, to cut the carbon intensity of freight transport operations, and many of these are self-financing. Harvesting this low-hanging fruit across the five areas of freight decarbonization may not deliver the required level of GHG savings but should get governments and businesses onto a path to truly low-carbon logistics by 2050.

Photo: Mscalora, Wikimedia Commons

Lake Side Power Station, a natural gas turbine power station in Vineyard, Utah. The freight sector has not adopted alternative fuels as readily as other sectors.

References

1. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report*. Intergovernmental Panel on Climate Change, Geneva, Switzerland, 2014.
2. Chapter 8: Transport. In *Climate Change 2014: Mitigation of Climate Change*. Intergovernmental Panel on Climate Change, Geneva, Switzerland, 2014.
3. *ITF Transport Outlook 2015*. International Transport Forum, Organisation for Economic Co-operation and Development, Paris, 2015.
4. Guérin, E., C. Mas, and H. Waisman (eds.). *Pathways to Deep Decarbonisation*. Sustainable Development Solutions Network and Institute for Sustainable Development and International Relations, Paris, 2014.
5. *Roadmap to a Single European Transport Area: Towards a Competitive and Resource-Efficient Transport System*. White paper. European Commission, Brussels, Belgium, 2011.
6. *EU Energy, Transport, and GHG Emissions: Trends to 2050–Reference Scenario 2013*. European Commission, Brussels, Belgium, 2014.
7. Hoekman, B. Trade and Growth: End of an Era. In *The Global Trade Slowdown: A New Normal?* Centre for Economic Policy Research Press, London, 2015.
8. McKinnon, A. C. *Options for Reducing Logistics-Related Emissions from Global Value Chains*. European University Institute, Florence, Italy. April 2014. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2422406.
9. Smith, A., P. Watkiss, G. Tweddle, A. McKinnon, M. Browne, A. Hunt, C. Treleven, C. Nash, and S. Cross. *The Validity of Food Miles as an Indicator of Sustainable Development*. Department of the Environment, Food, and Rural Affairs, London, July 2005.
10. *Freight Facts and Figures*. Bureau of Transportation Statistics, Federal Highway Administration, Washington, D.C., 2014.
11. *Competition Report 2013*. Deutsche Bahn, Berlin, 2013.
12. McKinnon, *A. European Freight Transport Statistics: Limitations, Misinterpretations, and Aspirations*. ACEA, Brussels, Belgium, September 2010.
13. http://cscmpbenelux.org/event-report-improving-transport-capacity-utilization/.
14. Clean Cargo Working Group. *Global Marine Trade Lane Emission Factors*. BSR, August 2014. www.bsr.org/reports/BSR_CCWG_Trade_Lane_Emissions_Factors.pdf.
15. *Cargo Chartbook Q2*. International Air Transport Association, 2015. https://www.iata.org/whatwedo/Documents/economics/cargo-chartbook-Q2-2015.pdf.
16. https://www.co3-project.eu/wo3/wp-content/uploads/2011/12/CO3-Deliverable-D4-3-Nestlé-Pepsico-STEF-case-study-Executive-Summary.pdf.
17. *Moving Freight with Better Trucks: Improving Productivity, Safety, and Sustainability*. ITF Research Report, Organisation for Economic Research and Development, Paris, 2011.
18. http://energy.gov/eere/vehicles/articles/supertruck-team-achieves-115-freight-efficiency-improvement-class-8-long-haul.
19. *U.S. Efficiency and Greenhouse Gas Emission Requirements for Model Years 2018–2027: Heavy-Duty Vehicles, Engines and Trailers*. International Council for Clean Transportation, Washington, D.C., 2015.
20. *Reduction of GHG Emissions from Ships: Third IMO GHG Study 2014*. Final report. International Maritime Organisation, London, 2014.
21. McKinnon, A. C. Freight Transport Deceleration: Its Possible Contribution to the Decarbonisation of Logistics. *Transport Reviews*, Vol. 36, No. 4, 2016, pp. 418–436.
22. *EU Transport in Figures: Statistical Pocketbook 2015*. European Commission, Brussels, Belgium, 2015.