Mobility and Transport Connectivity Series

Unlocking Green Logistics for Development

Richard Bullock | Martha Lawrence | Joanna Moody

WORLD BANK GROUP

© 2023 World Bank

International Bank for Reconstruction and Development / The World Bank
1818 H Street NW, Washington DC 20433

Internet: http://www.worldbank.org/transport

Standard Disclaimer

This work is a product of the staff of The International Bank of Reconstruction and Development / World Bank. The findings, interpretations, and conclusions expressed in this work do not necessarily reflect the views of Executive Directors of the World Bank or the governments they represent. The World Bank does not guarantee the accuracy of the data included in this work. The boundaries, colors, denominations, and other information shown on any map in this work do not imply any judgment on the part of The World Bank concerning the legal status of any territory or the endorsement or acceptance of such boundaries.

This work is available under the Creative Commons Attribution 3.0 IGO license (CC BY 3.0 IGO) http://creativecommons.org/licenses/by/3.0/igo. Under the Creative Commons Attribution license, you are free to copy, distribute, transmit, and adapt this work, including for commercial purposes, under the following conditions:

Attribution

Please cite the work as follows: Bullock, Richard, Martha Lawrence, and Joanna Moody. 2023. Unlocking Green Logistics for Development. *Mobility and Transport Connectivity Series.* Washington, DC: World Bank, License: Creative Commons Attribution CC by 3.0.

Translations

If you create a translation of this work, please add the following disclaimer along with the attribution: This translation was not created by the World Bank and should not be considered an official World Bank translation. The World Bank shall not be liable for any content or error in this translation.

Adaptations

If you create an adaptation of this work, please add the following disclaimer along with the attribution: This is an adaptation of an original work by The World Bank. Views and opinions expressed in the adaptation are the sole responsibility of the author or authors of the adaptation and are not endorsed by The World Bank.

Cover image: Adobe Stock
https://stock.adobe.com/in/images/global-transportation-industry/265671013?prev_url=detail

Acknowledgements

This report was written by Richard Bullock (Consultant), Joanna Moody (Transport and Climate Change Consultant), and Martha Lawrence (Senior Transport Specialist and Lead, Railway Solutions Group), with significant contributions from Megersa Abera Abate (Transport Economist), Goran Dominioni (Dublin City University), Dominik Englert (Economist), Matthias Plavec (Junior Professional Officer), Isabelle Rojon (Consultant), and Rico Salgmann (Consultant).

The work benefited from background research conducted by Richard Anderson (Imperial College London), Grace Ashley (Consultant), Benjamin Condry (Imperial College London), Jeremy Drew (Consultant), Jan Fransoo (Tilburg University), Ronald A. Halim (Equitable Maritime Consulting), Jan Havenga (Stellenbosch University), Richard Martin Humphreys (Lead Transport Economist), Alexandre Jacquillat (MIT Sloan School of Management), Chris Nash (University of Leeds), Alan McKinnon (Kühne Logistics University), Camilo Andres Mora Quinones (Tecnologico de Monterrey), Aditi Raina (Public Private Partnerships Specialist), and Lóránt Tavasszy (Delft University of Technology).

The team thanks the following people for reviewing and commenting on the report: Luis Blancas (Senior Transport Specialist), Jose Holguin-Veras (Director of the Center for Infrastructure, Transportation and the Environment, Rensselaer Polytechnic Institute), Charles Kunaka (Lead Transport Specialist), and Carolina Monsalve (Lead Economist).

This report was developed as part of the World Bank’s Decarbonization of Transport flagship activity led by Cecilia Briceno-Garmendia (Lead Economist) and Bianca Bianchi Alves (Senior Transport Specialist) with guidance from Nicolas Peltier (Director, Transport Global Knowledge Unit) and Binyam Reja (Practice Manager, Transport Global Knowledge Unit). Jonathan Davidar oversaw production and publication of this report, which was edited and designed by RRD GO Creative.

Table of Contents

Boxes

Figures

Tables

List of Abbreviations

3PL	Third-party logistics
AC	Alternating current
ATM	Air traffic management
BtL	Biomass-to-liquid
CCS	Carbon capture and storage
CH_4	Methane
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2e	CO_2 equivalent
CVRS	Computerized vehicle routing and scheduling
DFC	Dedicated freight corridor
DC	Direct current
EJ	Exajoules
ETS	Emissions trading system
EU	European Union
EV	Electric vehicle
gCO_2e	Grams of carbon dioxide equivalent
GHG	Greenhouse gas
GNI	Gross national income
Gtkm	Gross ton-kilometer
H_2	Hydrogen
HFO	Heavy fuel oil
HIC	High-income country
ICAO	International Civil Aviation Organization
ICE	Internal combustion engine
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
ITF	International Transport Forum
IWT	Inland waterway transport

kWh	Kilowatt-hour
LCV	Light commercial vehicle
LIC	Low-income country
LMIC	Low- and middle-income country
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
MJ	Mega joule
Mtoe	Million tons of oil equivalent
NDC	Nationally Determined Contribution
NH_3	Ammonia
Ntkm	Net ton-kilometer
OECD	Organisation for Economic Co-operation and Development
OPS	Onshore power supply
PLVB	Programa de Logística Verde Brasil
PtX	Power-to-gas/liquid
SAF	Sustainable aviation fuel
SBI	State Bank of India
SOE	State-owned enterprise
tCO_2e	Ton carbon dioxide equivalent
TEU	Twenty-four foot equivalent unit
tkm	Ton-kilometer
TTW	Tank-to-wheel
UK	United Kingdom
US	United States
WTW	Well-to-wheel/wake

Executive Summary

Mounting pressure for global climate action will lead to the profound transformation of logistics and supply chains. In low- and middle-income countries (LMICs), the demand for freight transport and other logistics activities is expected to increase for many years to come. Going forward, policymakers in LMICs must consider decarbonization of the logistics sector as an integral part of their economic and transportation planning and policy making. While an extensive body of logistics literature focuses on measures the private sector can take to reduce greenhouse gas (GHG) emission, this report focuses on the role that governments in LMICs must play in creating an enabling environment for decarbonizing logistics.

Greening logistics will require a holistic effort that covers all modes of transport and addresses both provision of infrastructure and transport and handling services. As logistics is a complex sector with many contributors to greenhouse gas (GHG) emissions, governments will need all potential "tools in the toolbox" to decarbonize the sector. These tools include:

- coordinating economic and transport infrastructure planning at the spatial level
- establishing a framework that discourages fossil fuel consumption
- encouraging a modal shift from road to rail and inland waterways
- facilitating the adoption of technologies and policies that improve the efficiency of logistics vehicles and operations and reduce fuel consumption
- shifting to alternative fuels

These interventions are summarized in table E.1. For most countries, efforts to decarbonize logistics will emphasize different interventions at different time periods, capturing readily available interventions at the beginning, and encouraging adoption of emerging technologies for fuel shift in the medium to long term.

Modal shift from trucks to lower-carbon modes is likely to be the single most impactful logistics decarbonization measure that can be taken in the immediate term. Where a country's freight is suited to rail or water transport, traffic shifted from road to those modes emits at least 70 percent fewer GHG emissions per ton-kilometer (tkm) transported even with existing fossil fuel-powered locomotives and barges.

The benefits of modal shift go well beyond climate—it can reduce transport costs, congestion, air pollution, and other externalities associated with road traffic. However, a range of interventions are typically needed to accomplish modal shift. These include:

- investing in and maintaining railway and waterway infrastructure
- ensuring that rail and water service providers operate commercially, and transport markets are competitive
- encouraging the development of logistics clusters with multimodal connections, particularly at the last mile
- promoting the growth of the third-party logistics sector to encourage multimodal logistics
- setting appropriate market conditions such as balanced infrastructure cost recovery from users and enforcing regulations

Table E.1. **Key Mechanisms and Actions for Decarbonizing Transport**

Sector (% of logistics GHGs)	Mechanism	Action	Fiscal Cost	Impact	Timing (years)
Framework Conditions	Discourage consumption of carbon-based fuels	• Eliminate subsidies & other supports for carbon-based fuels	Low	High	<5
		• Carbon pricing	Low	High	5-10
Trucking (54%)	Increase fuel efficiency of trucks	• Fuel efficiency standards for truck imports/sales	Low	Medium	<5
	Increase efficiency of truck operations	• Eliminate barriers to filling empty backhauls • Digital platforms development	Low	Medium	<5
	Shift to rail/inland waterway	• Balance cost recovery among modes/internalize external costs	Low	Low	<5
		• Invest in new infrastructure/upgrade existing rail & water infrastructure in appropriate markets. Support maintenance expenditure	Medium-High	Medium-High	5-10
		• Strengthen commercial governance of rail & water SOEs	Low	Medium	<5
		• Require logistics facilities to have rail/water connections where practical	Low	Medium	<5
	Electrify trucks in coordination with adequate supply and greening of the energy sector	• Ensure adequate electricity supply	Low-High	High	5-10
		• Support establishment of charging infrastructure	Medium	High	5-10
		• Subsidize electric trucks	High	High	5-10
		• Monitor developments in technology for medium and heavy trucks to implement technologies as they become established	Low	Low	5-10
Shipping (25%)	Shift fuels to green hydrogen or ammonia	• Apply carbon tax to carbon-based bunker fuels	Low	High	<5

Sector (% of logistics GHGs)	Mechanism	Action	Fiscal Cost	Impact	Timing (years)
Warehousing (9%)	Shift to solar power	• Include logistics facilities in programs encouraging rooftop solar	Low	High	<5
	Achieve greater energy efficiency	• Include logistics facilities in programs to encourage insulation, LED lights and other energy efficiency measures	Low	Medium	<5
Pipelines (6%)	Regulate methane emissions	• Penalize methane leaks and maintenance releases; Monitor pipelines for leaks.	Low	High	<5
Aviation (3%)	Shift to sustainable aviation fuels	• Apply carbon tax to traditional aviation fuel (kerosene)	Low	High	<5
		• Mandate use of sustainable aviation fuels	Low	Medium	5-10
		• Subsidize investment in sustainable fuel production and/or sales	High	Medium	5-10
Rail (3%)	Electrify traction in coordination with adequate, reliable supply and greening of the energy sector	• Support investment in overhead electrification when commercially viable	Medium	Medium	<5
		• Monitor developments in battery and hydrogen traction and plan to Implement technologies as they become established	Low	Low	5-10

Source: Original table produced for this publication.

In the long-term, a substantial share of logistics greening will come from alternative, low-carbon fuels. Over two-thirds of logistics GHG emissions come from trucking, shipping, and aviation, which can only be mitigated fully with fuel substitution. Alternative fuel technology is rapidly evolving, with electric batteries, hydrogen fuel cell, and other synthetic and biofuels being developed and piloted. When these options become available for commercial implementation at scale, achieving fleet turnover, replacing vehicles, and cascading alternative fuel options into secondhand markets in many LMICs is likely to take some years.

Image E.1. Containerized Freight Making a Multimodal Journey from Ship to Rail

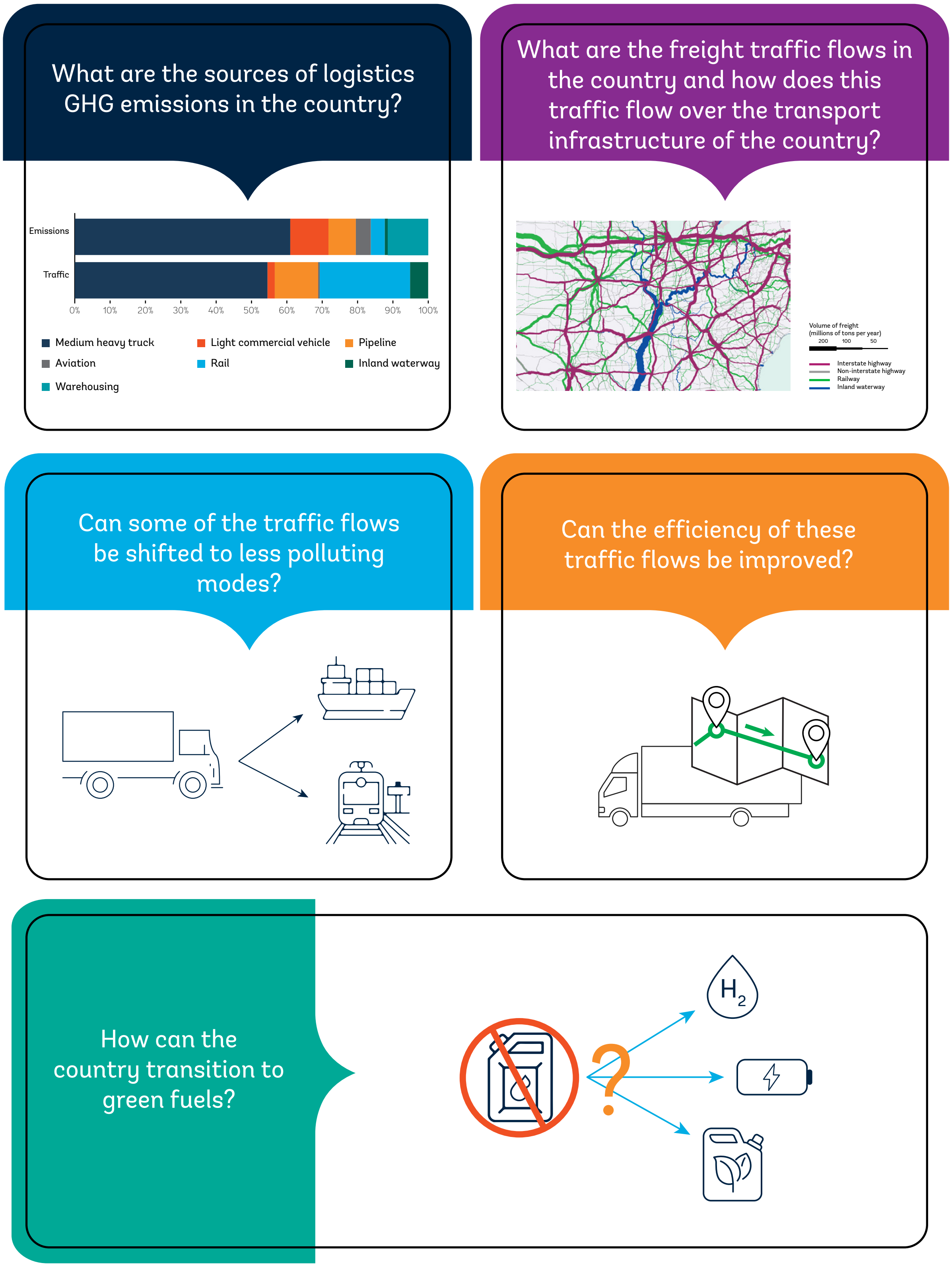
Source: Adobe Stock.

Decarbonization of logistics may bring particular opportunities for some LMICs. Countries with ample green electricity and good access to global markets may find that the fuel transition in logistics creates new economic opportunities for producing green hydrogen or ammonia. Other countries large enough to have a domestic vehicle manufacturing industry may find market opportunities in manufacturing green fuel vehicles. All LMICs can contribute to and prepare for the fuel shift by:

- participating in the international dialogue and cooperation on alternative maritime and aviation fuels
- preparing for disruptive changes in vehicle technology and fuels in the trucking sector, including putting in place motorization management processes that will be important for any vehicle/fuel transition
- scaling up green energy production to ensure that alternative energy sources are available and reliable

The right mix of policy tools to encourage a transition to cleaner and more efficient logistics will be different in every country. The World Bank encourages each country to create a Green Logistics Plan, which will incorporate climate considerations into the national logistics planning process. A Logistics GHG Analysis should be conducted to answer a few guiding questions regarding the state of logistics activities and their emissions (figure E.1). With this analysis, interventions can be prioritized for each country based on the local context, cost and ease of implementation, development impact, environmental impact, and the government's fiscal capacity. The World Bank is ready to support countries with this analysis.

Figure E.1. Developing a Green Logistics Plan



Source: Original figure produced for this publication.

1 Introduction

Key Messages

- **Freight transport and logistics is a critical enabler of economic and social development.**
- **The demand for logistics activity is expected to rise as LMICs grow. Under business-as-usual conditions, that growth will lead to substantial increases in GHG emissions. Therefore, decoupling the growth in logistics activity from the growth in GHG emissions is urgently needed.**
- **GHG emissions from logistics have many components so tackling them will require a holistic set of policy, pricing, regulatory, and technical mitigation measures.**
- **This report synthesizes existing evidence on potential logistics GHG mitigation measures, with chapters focused on the role of spatial planning and economy-wide pricing measures, modal shift, efficiency improvements, and fuel shift.**
- **Efficient logistics is typically greener than inefficient logistics, and many GHG-mitigation actions improve the efficiency and reduce the cost of logistics. However, while improving a country's logistics sector can go hand-in-hand with reducing emission, this alone is not sufficient to fully green the sector.**
- **The right mix of measures will be different for each country, and they can be incorporated into an overall Green Logistics Plan.**

1.1. Economic Growth, Logistics, and GHG Emissions

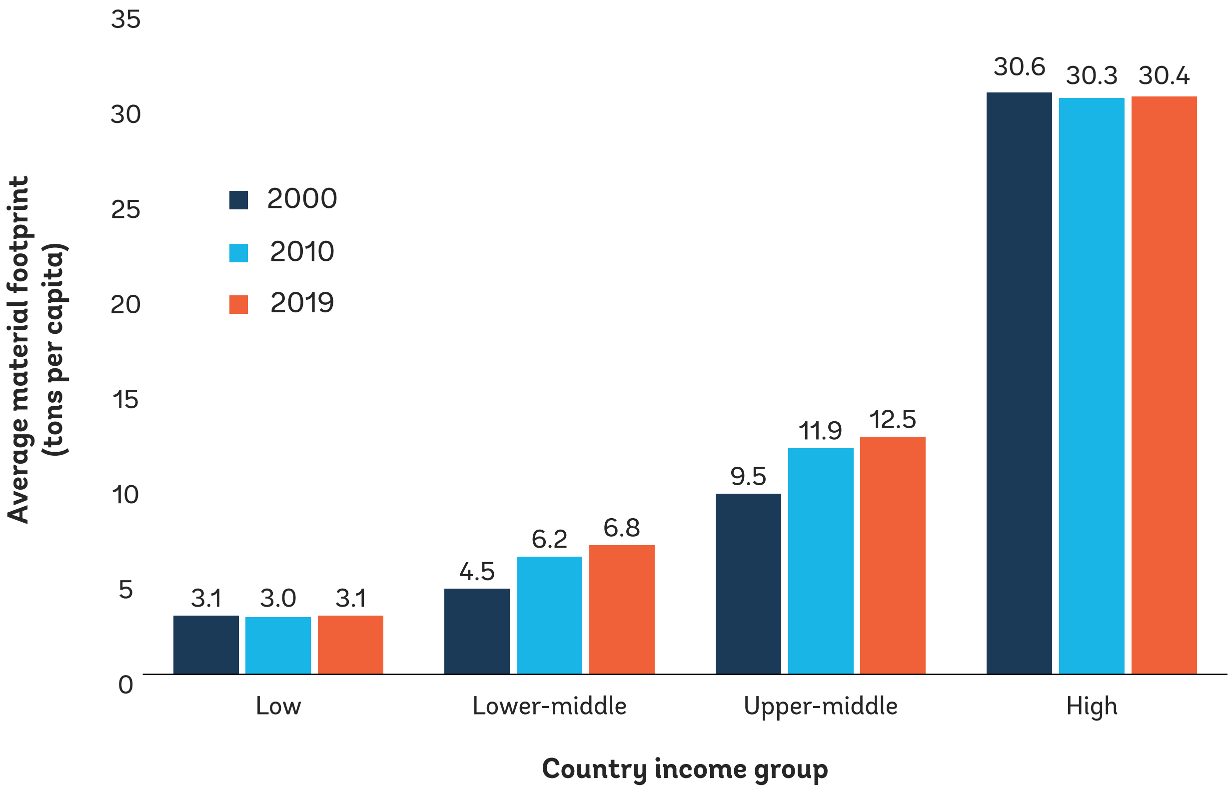
Logistics[1] activities are critical enablers of economic and social development. At the macroeconomic level, logistics performance is strongly correlated with national economic growth and competitiveness (Jayathilaka et al. 2022; World Bank 2018). Better logistics reduces the cost of production in most industries by making it faster and cheaper to obtain parts and raw materials and to take finished products to market. Conversely, inefficient logistics raises the cost of doing business and reduces the potential for integration with global value chains. The toll can be particularly heavy for LMICs trying to compete in the global marketplace.

Having inefficient or inadequate transportation, logistics, and trade-related systems can severely impede a country's ability to compete on a global scale. The modern era of international trade is one of increasingly complex interactions among people, firms, and organizations. This has serious implications for the world's poor, who often are disproportionately disconnected from global, regional, and even local markets. Poverty is often concentrated in geographic areas that are poorly connected to active economic centers, within and between countries. These pockets of poverty often lack good connections to financial, economic, information, and infrastructure networks. Firms and communities in these areas miss opportunities to develop skilled, competitive workforces; they are not integrated with global production chains and are less able to diversify their products and skills.

[1] Typically, logistics systems consist of five elements: (1) storage, warehousing, and materials handling, (2) packaging and unitization, (3) inventory, (4) freight transport, and (5) information and control. This paper focuses on the decarbonization of freight transport and storage, warehousing, and materials handling as the primary sources of GHG emissions from logistics systems, while touching only lightly on other elements.

Historically, a strong relationship has existed between freight activity and GDP growth. Data from the UN Environment Program's International Resource Program indicate that the volume of materials handled per person in high-income countries (HICs) is about five times that of low-income countries (LICs) (figure 1.1). This relation suggests that, as incomes rise in LICs, the volume of goods handled is likely to rise as well.[2]

Figure 1.1. Average Materials Footprint (Tons Per Capita) by Country Income Group, 2000-2019



Source: World Bank analysis based on data from the UN Environment Program's International Resource Panel. https://www.resourcepanel.org/global-material-flows-database.

Notes: Country income groups as classified by gross national income (GNI) per capita calculated using the World Bank Atlas method. Low-income economies are defined as those with a GNI per capita of $1,135 or less in 2022; lower middle-income economies are those with a GNI per capita of $1,136 to $4,465; upper middle-income economies are those with a GNI per capita of $4,466 to $13,845; and high-income economies are those with a GNI per capita of $13,845 or more. https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups.

While greater access to goods, services, and markets has clear economic and social benefits, the associated logistics activities create negative environment and public health impacts, including air pollution and GHGs. In 2019, global freight transport totaled approximately 140 trillion net ton-kilometers (ntkm).[3] Its activities generated an estimated 5.2 million tons of "well-to-wheel/wake" (WTW) GHG emissions,[4] nearly 10 percent of total global emissions.

[2] The IRP data suggest that the relation between freight activity and income may be weakening for HICs; this is likely to be explained by the relative importance of the service sector in the economy (ITF 2017) and the off shoring of manufacturing to LICs (McKinnon 2018).

[3] A ntkm represents the movement of one ton of freight for one kilometer. A road truck carrying 10 tons of freight for 100 km would produce 1000 ntkm. All tons in this report are metric tons. When the measure includes both the weight of the freight and the vehicle, it is indicated as gross ton-kilometers. When the measure does not indicate net or gross, it should be understood as net.

[4] WTW estimate includes the emissions created in the energy sector to produce the fuel/electricity that powers the transport.

As LICs expand trade and logistics activities to develop their economies, the demand for goods movement is expected to increase for many years to come. In a business-as-usual scenario, the total freight demand (domestic and international) is projected to reach 329,000 trillion tkm by 2060 (ITF 2017). This growth in demand is largely driven by economic growth in LMICs. Freight volumes are expected to increase by a factor of 3 in non-Organisation for Economic Co-operation and Development (OECD) economies (to make up nearly 80 percent of all surface freight transport demand in 2050) while increasing by a factor of 1.6 in OECD countries during the same period (ITF 2017).

Despite the importance of meeting climate goals in the logistics sector, these goals remain inadequately represented in Nationally Determined Contributions (NDCs) to the Paris Agreement, the International Civil Aviation Organization (ICAO) State Action Plans, and in global agreements on international shipping. Only a few second-generation NDCs include logistics actions: "While the large majority of mitigation actions in second-generation NDCs do not specify which type of transport activity to which they apply, of the mitigation actions that are specific, only 17 percent refer to freight transport while 73 percent mention passenger transport; the remaining 10 percent include a combination of passenger and freight transport" (SLOCAT 2022). Only a few countries have expressed their intention to increase their engagement in global agreements on aviation and shipping. Efforts to minimize their aviation and shipping emissions will be addressed through their active participation in ICAO and International Maritime Organization (SLOCAT 2022).

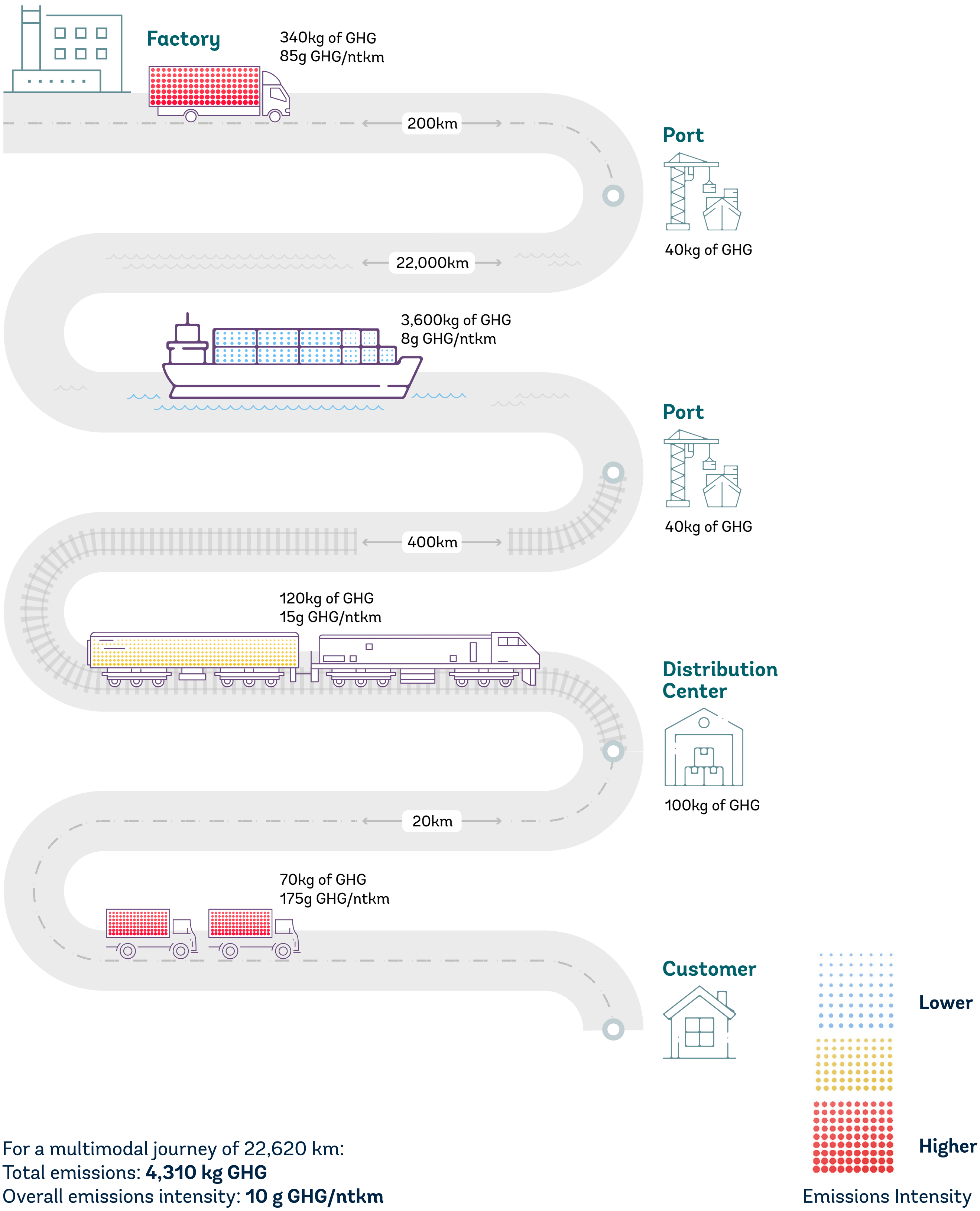
1.2. Components of GHG Emissions from Freight and Logistics

The logistics sector includes a wide range of activities related to the transport and handling of goods. These include, but are not limited to:

- long-distance transport, such as the shipment of a container from a manufacturer in China to a customer in Europe (figure 1.2)
- regional transport, such as a consumer product moving from a manufacturer to a regional warehouse from where it is distributed on a pallet to the end-user
- local transport, such as construction materials (sand, gravel) moving from a quarry to a construction site
- urban deliveries covered in a companion report entitled *Decarbonizing Urban Transport for Development*
- operation of freight handling facilities, such as warehouses and terminals

Freight trips, especially international ones, are often multimodal, and the choice of mode can have significant implications for the carbon footprint of the end-to-end trip. Many freight shipments combine several modes and handlings at logistics facilities; the total emissions of such shipments and average emissions per ntkm would reflect the mix of modes used (see figure 1.2).

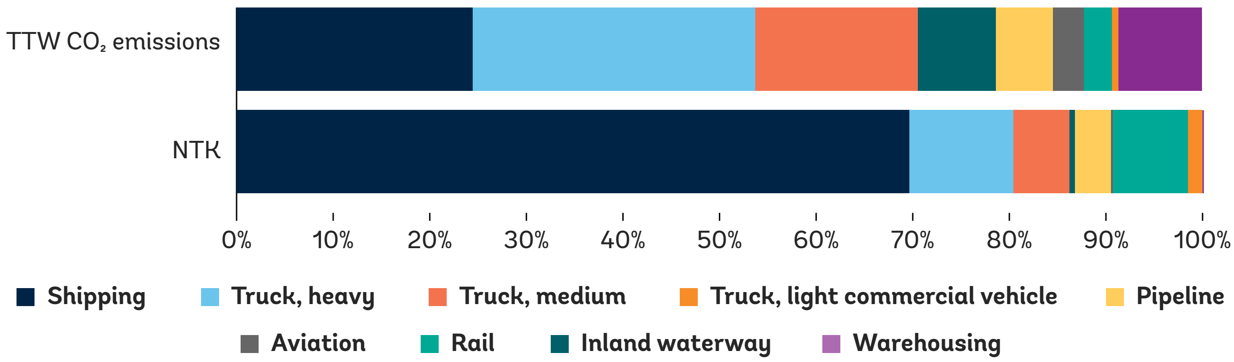
Figure 1.2. **Logistics Emissions Example: Long-distance transport of a 20 ton container of goods**



For a multimodal journey of 22,620 km:
Total emissions: **4,310 kg GHG**
Overall emissions intensity: **10 g GHG/ntkm**

Today, global freight transport is dominated by maritime shipping, which carries over 70 percent of total ntkm. Road freight by heavy and medium trucks carries an additional 15 percent, with rail at 8 percent (figure 1.3). As some modes operate with greater energy efficiency and cleaner fuels than others, the proportion of traffic carried by mode does not equate to the proportion of GHG emissions contributed by mode. For example, while road freight transport carries only 15 percent of the global ntkm, it contributes as much as 54 percent of GHG emission from freight and logistics. Maritime shipping contributes 24 percent of freight and logistics emissions. Warehousing/handling of goods generates about 9 percent, pipeline transport about 6 percent, and rail, air freight, and inland waterway transport (IWT) a few percent each.

Figure 1.3. Share of Global Logistics ntkm and Estimated Tank-to-wheel (TTW) CO_2 Emission by Mode



Source: IEA, supplemented by World Bank Analysis.

Note: Warehousing includes freight handling facilities.

1.3. Scope of this Report

This report examines the opportunities to decouple growth in logistics activity from growth in GHG emissions, synthesizing existing evidence on potential GHG mitigation measures. It focuses on non-urban logistics. Urban logistics is covered in a companion report on decarbonizing urban transport. Chapters 2 to 5 cover the main types of interventions available to reduce GHG emission. Chapter 2 examines how spatial planning and land use can affect logistics GHG emission and economy-wide pricing measures provide economic incentives for decarbonization. Chapter 3 discusses the potential for a modal shift to lower emissions transport modes. Chapter 4 addresses opportunities for improving energy intensity through technical efficiency and capacity utilization. Chapter 5 explores the potential of alternative fuels for freight transport and energy sources for warehousing.

Chapter 6 brings together the various policy interventions and suggests how LMICs can analyze and prioritize interventions as part of their overall national logistics planning. An efficient logistics system is greener than an inefficient one, so many of the "quick win" interventions to reduce GHG emissions will also improve the efficiency and reduce the cost of a country's logistics. The best mix of measures will be different for each country and can be integrated into each country's development of a Green Logistics Plan.

2 Setting Economy-wide Framework Conditions for Green Logistics

Key Messages

- **As logistics activities grow in LMICs, it is critical for governments to set economy-wide framework conditions properly to support both efficiency and decarbonization.**
- **Coordinated spatial planning of economic activity, transport infrastructure, and logistics facilities can have significant impacts on the efficiency of logistics supply chains and their emissions. For example, by providing rail and water infrastructure connectivity or ensuring that existing services are reliable, governments can encourage the private sector to cluster logistics activities in 'freight villages.'**
- **Governments can influence how firms structure their supply chains by pricing transport infrastructure, fuels, or carbon emissions directly.**

As logistics activities grow in LMICs, it is critical for governments to properly set economy-wide framework conditions to support both efficiency and decarbonization. Reflecting national economic development goals, coordinating the spatial planning of goods production and consumption with the provision of logistics infrastructure and facilities encourages efficiency and reduced emissions. While such measures can guide the private sector's investment decisions, additional measures that price the environmental impacts of logistics activities are likely to be needed for firms to fully account for the social cost of climate change in their supply chains.

Companies typically try to optimize across their entire production, distribution, and selling operations, factoring in market requirements and each segment's costs, characteristics, and constraints. The more the individual costs (especially transport and energy) borne by the company reflect those of a decarbonized economy, the more companies will be encouraged to decarbonize their logistics chains.

2.1. Supply-chain and Spatial Planning

Where and how goods flow in a country is largely shaped by where the freight-is generated, processed, and consumed; the type of goods traveling between these points; and the transport infrastructure connecting them. Therefore, coordinated spatial planning of economic activity, transport infrastructure, and logistics facilities can have significant impacts on the efficiency of logistics supply chains and their emissions. Network-level supply chain reorganizations, such as the planned development of warehousing facilities and the concentration of logistics activities in 'freight villages,' can consolidate freight flows. The allows the logistics system to meet the needs of diversifying and developing economies in a lower-carbon way. While public-sector spatial planning and pricing policies have a role to play in shaping these supply chain decisions, this is also an area for active private sector participation and investment mobilization (for example, by real estate developers and third-party logistics [3PLs] service providers).

Government economic policies that affect the spatial distribution of economic activity can significantly affect the level of logistics activity and the GHG emissions that result from it. For example, countries such as China have adopted policies focused on relocating manufacturing or other economic activity from richer to poorer areas of the country to address spatial economic disparities.

In establishing these policies, governments should carefully consider the implications for logistics activities and their GHG emissions, and, where possible, ensure connectivity of special economic zones and other areas of industrial development to high-efficiency and low-emissions modes such as rail and waterway.

One way to minimize GHG emissions from logistics is to assess the location of production sites and warehouses to identify opportunities to reduce tkm traveled. While straightforward in concept, the globalization of supply chains and other trends adopted for economic efficiency have worked against efforts to minimize freight transport activity and related GHG emissions. Global value chains tend to have more intensive use of transportation than other types of trade. Parts and components are shipped to a country only to be shipped out after assembly. This back-and-forth transport of goods across long distances, currently powered almost exclusively through the combustion of fossil fuels, generates GHG emissions that directly contribute to climate change (World Bank 2020).

The optimal supply chain arrangement for the private sector may not always be the minimum GHG emissions arrangement. At a regional and national level, the trend over the past few decades has been to concentrate inventory and related materials-handling activities in more centralized facilities. This approach allows companies to serve wider areas more quickly, reliably, and cheaply as well as make the most of the 'square root law of inventory' (McKinnon 2018). At the same time, the concentration of activities in centralized facilities reduces the carbon intensity of warehousing operations by reducing energy consumption per unit of throughput (Baker and Marchant 2015). However, these gains are often more than offset by the additional GHG emissions generated from the transport and delivery of goods over longer distances to and from fewer locations (McKinnon 2018).

In the absence of coordinated economic and transport planning that provides multimodal connectivity, centralization can lead to more freight transport activity and emissions. Since warehousing accounts for only a small percentage of the total emissions from freight and logistics, its emissions savings from centralization are dwarfed by the increases in emissions from goods transport to and from the centralized facility, depending on the mode used (McKinnon 2018). In many cases, the location of the central supply point has also changed from cramped inner-city sites (connected to the rail network, but with congested local road connections) to new outer-suburban sites well-connected to highways.[5] This has resulted in more goods distributed by road. While the overall tkm may not be very different, more of the transport is by truck. As trucks are less fuel-efficient than rail, the fuel use can increase significantly (by a factor of about four) relative to the previous rail movement. In some LMICs where economic activity is still dominantly agricultural, seasonal variations and short shelf lives make consolidation of goods flows more challenging and the time-responsiveness of the trucking sector more attractive, especially when proper storage facilities with appropriate temperature controls are lacking.

When consolidation plans consider multi-modal connectivity, ideally as part of a National Logistics Strategy, efficient logistics with lower emissions will result. By providing rail and water infrastructure connectivity or ensuring that existing services are reliable, governments can encourage the private sector to cluster logistics activities in 'freight villages' or integrated logistics centers. Choosing where to make these strategic infrastructure investments should be a part of a National Logistics Strategy that analyzes the economic activities and freight flows in the country,

[5] In others, manufacturing has relocated completely from high-income countries to low- and middle-income countries, undoubtedly increasing total freight traffic.

coordinates the country's plans for economic development with its national transport planning, and proposes the optimum location for facilities based on cost, emissions, and other factors. This can be a starting point for discussions with private sector developers and investors for public private partnerships in logistics infrastructure.

2.2. Pricing Measures

In addition to providing infrastructure and improved warehousing facilities, governments can influence how firms structure their supply chains through pricing measures. Governments have significant influence on the transport prices customers pay and the relative prices of different modes. Pricing mechanisms are generally viewed as efficient measures to support strategies to reduce emissions. This is primarily due to their broad coverage, extensive duration, and potential level of ambition achieved by one policy (Tvinnereim 2014). Over time, properly calibrating these pricing measures will send the correct economic signals and provide incentives for a broad range of actions by freight shippers, receivers, and consumers to reduce GHG emissions. These actions could include:

- improving fuel efficiency of vehicles
- enhancing efficiency of operations
- shifting to less GHG-emitting modes
- adopting green technologies

Some pricing measures impact the cost of using certain freight transport infrastructure. Examples include road-use charges and tolls for roads and access charges for rail. How these prices are set has a significant influence on which modes shippers use and hence the emissions from their logistics (see Chapter 3). Differential pricing across types of vehicles for a given mode can also influence the choice of technology. For example, in Switzerland, heavy-duty trucks that run on diesel pay a hefty road tax; however, vehicles with zero tailpipe emissions such as battery electric or fuel cell trucks are exempt from the tax. This has encouraged companies to pilot new truck technologies.

Other pricing measures target the fuel consumed by freight transport. To guide greener logistics, governments can rethink their taxation or subsidy policies around fossil fuels used for freight transport. For example, in 2015, Indonesia reduced its subsidies for diesel and gasoline by 80 percent, lowering incentives to use high-emitting transport and resulting in approximately $20 billion becoming available for other programs. Phasing out subsides for carbon-based fuels is often politically sensitive and needs to be coupled with programs to offset the impact on vulnerable citizens. It may also have implications for economic growth and may have to be done gradually to avoid "shocking" the economy (box 2.1).

Box 2.1. Fuel Subsidy Reform in Mexico

Pricing and taxing measures, such as phasing out existing fossil fuel subsides, can give economy wide incentives to reduce consumption of fossil fuels that will directly impact freight logistics. However, reducing such subsidies can have significant social costs and an impact on economic growth, as in many cases communities and especially smaller freight companies) rely heavily on them. Research suggests that the revenue earned from the removal of fuel subsidies can be used to mitigate any negative impacts of such reforms.

A successful example is Mexico's fuel pricing and taxation reform, which has been noted as one of the most ambitious recent global reform efforts. The country shifted from heavy support for gasoline, diesel, and liquefied petroleum gas (LPG) to net positive taxes through the reform of the Impuesto Especial Sobre Producción y Servicios, a floating excise tax. The market for LPG was fully liberalized at the beginning of 2017. The 2016 price increases for gasoline and diesel were held within 3 percent of 2015 prices, and a maximum price shift of up to 20 percent for gasoline was allowed in 2017. These price limits guaranteed the avoidance of any sudden price shocks and gave impacted sectors more time to adapt (OECD 2021).

Carbon pricing mechanisms can provide additional incentive to reduce GHG emissions. Carbon pricing mechanisms have two main variants, emissions trading systems (ETSs) and carbon taxes. The ETS approach sets a baseline or a cap on emissions and creates a market for trading emissions credits. Carbon taxes are charged for GHG emissions and are often levied on the sale of fossil fuels, including fuel for transport. More than 60 countries and regions have implemented a carbon pricing mechanism to discourage GHG emissions, with around half of those mechanisms being ETS and the other half being carbon taxes. Approximately a third of these mechanisms apply to transport.

Carbon prices must be set at a meaningful level to be impactful. Worldwide, carbon prices range from less than \$1 to \$120 per ton CO_2 equivalent (tCO_2e). Prices in LMICs typically hover on the lower end. For example, Argentina charges \$5 per tCO_2e or \$0.02 (¢2) per liter of fuel (World Bank 2022). This is less than 1 percent of the total fuel price in Argentina (Climate Transparency 2020) and was designed to have minimal immediate impact on the price of fuel, as it replaces a gasoline tax. Such a low price is unlikely to change transport behavior substantially or have a strong impact on transport GHG emissions. The price of carbon will need to be significant enough to influence production and distribution decisions made by firms and consumption decisions made by individuals. The Report of the High-Level Commission on Carbon Price indicates that a global carbon price would need to be set in the range of \$50-100/tCO_2e by 2030 to keep global warming to 2°C. However, low price elasticities of demand often measured in transport suggest that carbon prices might need to be even higher to make a meaningful impact on freight demand and influence the spatial structures of supply chains. This presents a significant challenge for LMICs where fuel and transport costs are already a significant share of the cost of goods. Therefore, for carbon prices to work, they must be set only after careful considerations of affordability, appropriate policies to alleviate impacts on the most vulnerable, and the provision of other measures to give firms and individuals alternatives to high emitting activities (World Bank 2023).

Given the truly global nature of the aviation and shipping sectors, especially when ships can easily change their flags (country affiliation), carbon pricing policies should be adopted as globally as possible. This relates, for instance, to global policymaking at the IMO, or at least regional policymaking as adopted by the European Union. If appropriate, governments can also take policy action at the national level as long as the risk of carbon leakage can be contained.

Pricing/taxing mechanisms work most effectively if attractive alternatives to high carbon transport are available. If not, they risk increasing the cost of logistics without a significant reduction in GHG emissions. Thus, when introducing pricing/taxing measures, governments need to simultaneously improve the availability of lower-carbon transport alternatives.

Fuel and carbon taxes can play an important role in funding and financing transport climate actions. Studies of financing low carbon transport emphasize that using such funds for green purposes is key. “Investment in increasing the transport infrastructure capital stock has primarily been channeled toward expanding the highway network through road construction, resulting in increasing motorization rates and motorized vehicle activity” (Benitez and Bisbey 2021). Instead, these taxes can be directed toward supporting green transport service or leveraged as a funding stream to underpin the financing of green transport investments.[6]

Image 2.1. Fuel Storage Tank and Access Road in Mexico

Source: Adobe Stock.

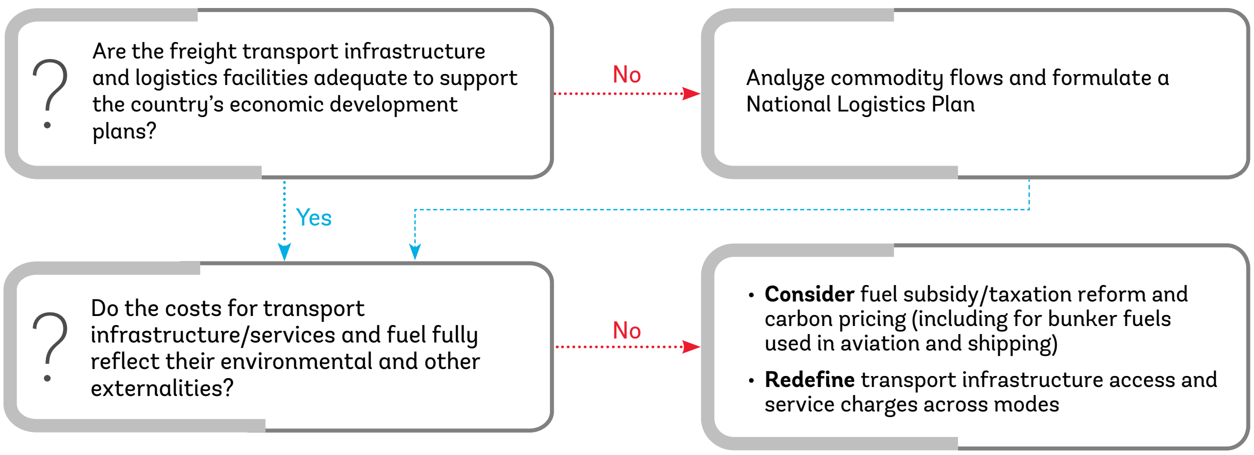
6 More information on climate financing can be found in Benitez and Bisbey (2023).

Governments should consider the pricing of carbon-based fuels not only as a deterrent to their use but also as a revenue source to offset distributional impacts of pricing measures and to support scale-up of innovation. This is particularly important in the international maritime and aviation sectors. A revenue-raising carbon pricing instrument would not only reduce GHG emissions most cost-effectively, but could also create a new, additional source of climate and development finance—a unique feature not offered by any policy considered above (Dominioni and Englert 2022). This unique source of climate and development finance from the private sector could then be used to support countries around the world, especially LMICs and most importantly, small island developing states and least developed countries, in their climate change mitigation and adaptation efforts (Dominioni and Englert 2022). It could also be leveraged to support the national climate action (for example, feed-in tariffs, direct subsidies, fiscal incentives, or green procurement) discussed in later sections of this report. This strategic use of carbon revenues appears more favorable in addressing equity concerns than granting any exemptions to LMICs; the latter could lead to unwanted market distortions internationally.

2.3. Getting the Framework Conditions Right

Figure 2.1 outlines the series of questions that will guide countries in setting the right economy-wide framework conditions for efficient and green logistics. The first step is to understand current and future commodity flows based on economic development plans, formulating a National Logistics Plan that guides the development of efficient logistics and identifies where additional transport infrastructure and logistics facilities may be needed. After this spatial transport and economic planning, policymakers can then ask whether the costs for transport infrastructure, services, and fuels adequately reflect their environmental and other externalities. If not, subsidy and taxation schemes can be revisited to internalize GHG emissions costs.

Figure 2.1. Key Questions and Policies for Setting Economy-wide Framework Conditions for Green Logistics



Source: Original figure produced for this publication.

3

Shifting to Lower Emission Modes of Freight Transport

Key Messages

- **Shifting freight traffic from high GHG-emission modes (road and air) to lower emission modes (rail and water) can substantially reduce emissions.**
- **Only some traffic can be shifted. Rail and water transport are more competitive for traffic that has larger consignment size, moves long distances, has lower freight value, and whose production/consumption points are directly connected to rail/water.**
- **Countries can analyze their freight markets by these characteristics to assess the potential competitiveness of rail and water transport. They may aim to shift most or all the rail/water-dominant traffic and a share of rail/water-competitive traffic.**
- **Government measures to encourage modal shift include investing in and maintaining railway and water infrastructure in good condition, ensuring that rail and water service providers operate commercially, encouraging multimodal connections to logistics facilities, and setting appropriate market conditions such as balanced infrastructure cost recovery from users and enforcement of regulations.**

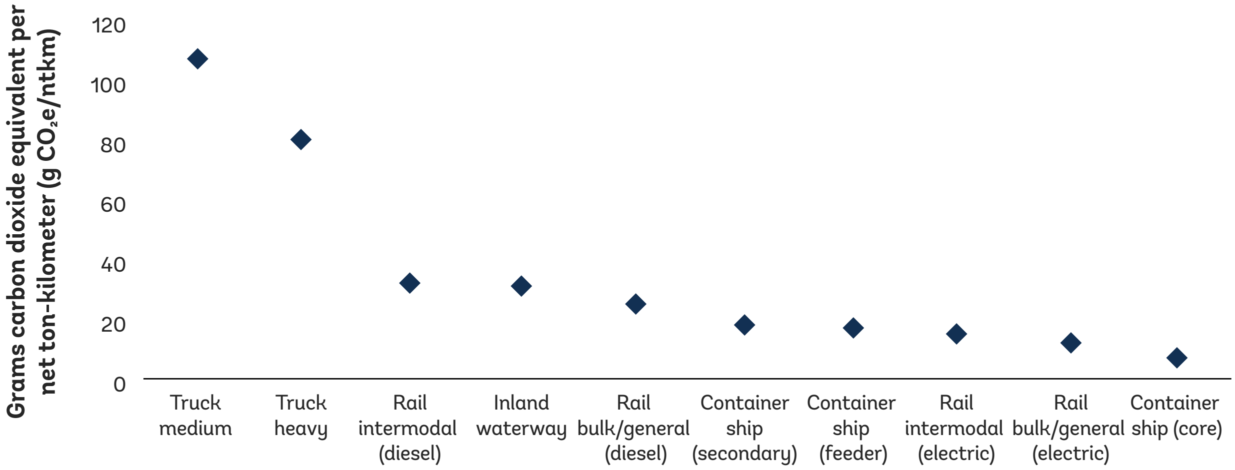
Freight transport modes have different average emission intensities, expressed as grams of CO_2e (gCO_2e) emitted per tkm of goods transported (figure 3.1). These averages per mode depend on their typical technical efficiency (fuel consumption), operating efficiency (freight load), and fuel type. Specific freight movement emissions will vary depending on the circumstances of the movement. For example, freight train emissions per tkm depend on the terrain, the size of the train, and the speed at which it operates and can easily vary by ±50 percent on an average estimate.

As long as road transport remains diesel-powered, it will be the most carbon-intensive land-based mode of freight in almost all circumstances. On a per tkm basis, heavy and medium diesel trucks typically generate four to five times the GHGs emission as rail per unit of work. Diesel-powered small vehicles, which are used for ‘last-mile’ deliveries, can generate another four times as much emissions. In contrast, maritime shipping, particularly with large container vessels and bulk carriers, typically has the lowest emissions per tkm. Only electric-powered rail services operating on low-carbon electricity are comparable. Diesel rail has higher emissions per tkm than maritime shipping, as do inland waterways and pipelines, but is still significantly lower than road.

Image 3.1. A Train Carrying Phosphate Ore in Saudi Arabia

Source: Saudi Railway Company, SAR (2014).

Figure 3.1. Typical Traction-related Emissions Intensities for Freight Transport by Mode (gCO_2e per ntkm)



Source: Adapted from Lawrence and Bullock (2022, pg. 8).

Due to the stark differences in average emission intensities across modes, shifting freight kilometers traveled from higher GHG emitting transport modes—such as trucks and airplanes—to available lower GHG emitting transport modes—such as maritime shipping, inland waterway (IWT), and rail can achieve immediate GHG emissions reductions. On a per tkm basis, shifting traffic can save 70-80 percent of GHG emissions from road transport.

The transport decarbonization strategies of many countries include goals of shifting freight traffic from high GHG-emitting modes to lower GHG emitting modes. Such policy aims are not new, as modal shift will also reduce transport costs, road congestion, air pollution, and other externalities associated with road and air transport. Investing in alternatives to road transport can bring wide-ranging benefits beyond just climate.

Many countries have the potential for shifting freight to less energy-intensive modes. However, the ease of achieving this varies by country and depends on many factors including the availability of good quality infrastructure and services on alternative modes and the distance of freight movement and type of freight traffic. In the EU, many years of effort to promote modal shift have, at best, kept the rail and inland waterways shares steady. Even in the US, where rail is commercially managed, customer-oriented, and significantly cheaper than road, it has a 35 percent share of the surface freight market.[7] Water transport, largely based around the Mississippi and Great Lakes, has about 12 percent share.

3.1. Opportunities for Modal Shift

How much freight traffic can be shifted from road to rail or IWT in any country depends, in substantial part, on how much of the freight in the country, currently moving by truck, can realistically be carried by rail or inland waterway. While rail and water transport provide lower cost for linehaul movements, shippers consider total door-to-door costs and a whole range of transport

[7] Surface freight excludes pipelines, which carry 16 percent of total freight tkm in the US.

characteristics when selecting the transport mode. Important characteristics in determining the attractiveness of rail and water transport include minimum consignment size, freight value, last-mile connectivity, and distance.[8]

- *Minimum consignment size.* A long-haul truck can carry up to 45 tons, while a rail wagon holds 70–110 tons (with many wagons per train), and a barge can load 12,500 tons. This means that rail and inland water transport are more suited to carrying bulk products (shipped in large quantities) than manufactured products, which tend to be transported in smaller quantities. It is possible to palletize, consolidate, and containerize smaller shipments for rail and water transport, but this adds handling time, handling cost, and potential unreliability to the transport (Aritua 2019). One exception is port traffic, which is already consolidated and containerized for international shipping. Rail and inland water transport can be more competitive for the domestic transport of this traffic.

- *Freight value.* Where more than one mode is available for freight shipments, the choice will always involve a trade-off between transport cost and perceived service attributes such as speed, security, and reliability of delivery.[9] Transport cost becomes less important as the value of the freight increases; for high-value products, transport is a smaller component of the delivered cost for the customer. This is reflected in modal choice, with shippers of higher-value freight choosing faster modes with high level of service reliability and shippers of lower-value freight choosing a mode primarily based on transport cost.

- *Last-mile connectivity.* Rail and water are the most competitive when they directly serve the origin and/or the destination of the traffic. When freight must be picked up or and/or distributed to destination by truck, additional handling costs, time, and potential unreliability are incurred.

- *Distance.* The longer the shipment distance, the greater the cost advantages of rail and water, relative to truck.

Image 3.2. Barge with a Load of Sand on the Mekong River, Cambodia

Source: gordontour (2023).

[8] Seasonality can also influence mode choice if it affects the availability and reliability of service. For example, when parts of the upper Mississippi River freeze in winter, shipments may move to rail or truck (NAS 2019).

[9] These determine the cost of holding inventory in supply chains, most of which is the sum of transport costs and inventory carrying costs.

These characteristics are different for various commodities and help explain why some traffic is more susceptible to modal shift than others. Table 3.1 shows typical characteristics by commodity.

Table 3.1. Commodity Characteristics Affecting Mode Choice

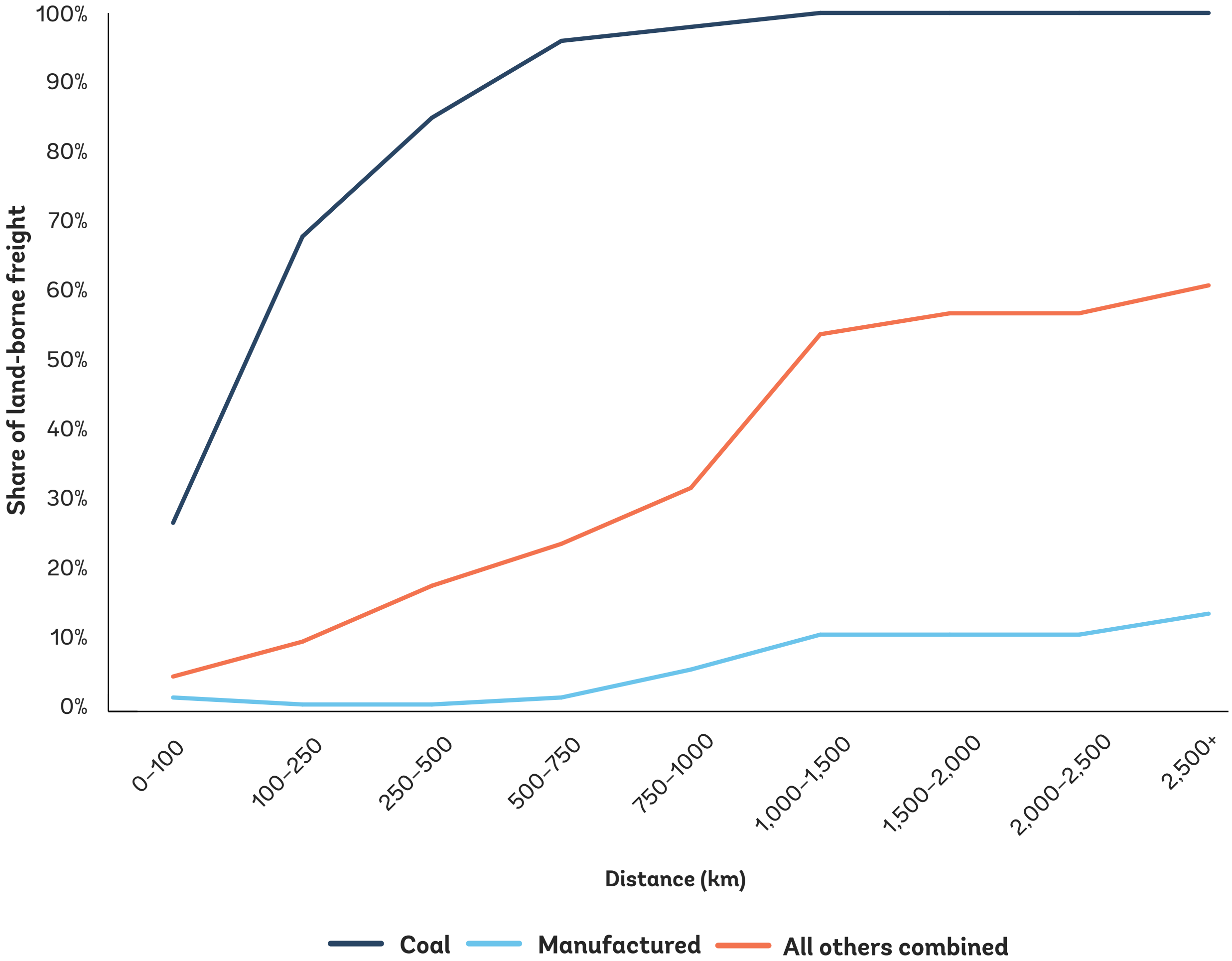
Commodity	Consignment Size	Value/ ton	Directly Rail Served	Directly Water Served
Consumer Products	Small	High	Many ports (with product consolidated and containerized)	Many ports (with product consolidated and containerized)
Industrial Products	Medium	Medium	Some production facilities and receivers, many ports (with product consolidated and containerized)	Few production facilities and receivers, many ports (with product consolidated and containerized)
Agricultural Products	Large / Medium	Low	Many consolidation points, some processing facilities, many ports	Some consolidation points and processing facilities, many ports
Petroleum	Large	Medium	Many extraction points, processing facilities and ports, some end-users	Some processing facilities and many ports
Minerals	Large	Low	Many mines, processing facility and ports	Some processing points and many ports
Coal	Large	Low	Many mines, consumption points, and ports	Some consumption points and many ports

Source: Original table produced for this publication.

The combined effect of these influences is demonstrated in figure 3.2, which shows the cumulative share for rail of different commodities by distance in the US market.[10] In the US, both rail and truck offer a comparatively high level of service. Coal traffic (average value $38/ton) overwhelmingly moves by rail at distances of 250 km or greater. At the other extreme, rail's share of manufactured goods (average value of $3700/ton) is negligible for distances under 750 km and only carries around 15 percent at distances of 2500 km. For the other groups of commodities (agriculture, other minerals, and liquids with average value of $600/ton) rail begins to be competitive at around 500 km and handles over half the traffic moving 1500 km or more.

[10] The US railways offer a high level of service and, in 2020, carried 27 percent of freight measured by tkm (US Department of Transportation, Bureau of Transportation Statistics 2022).

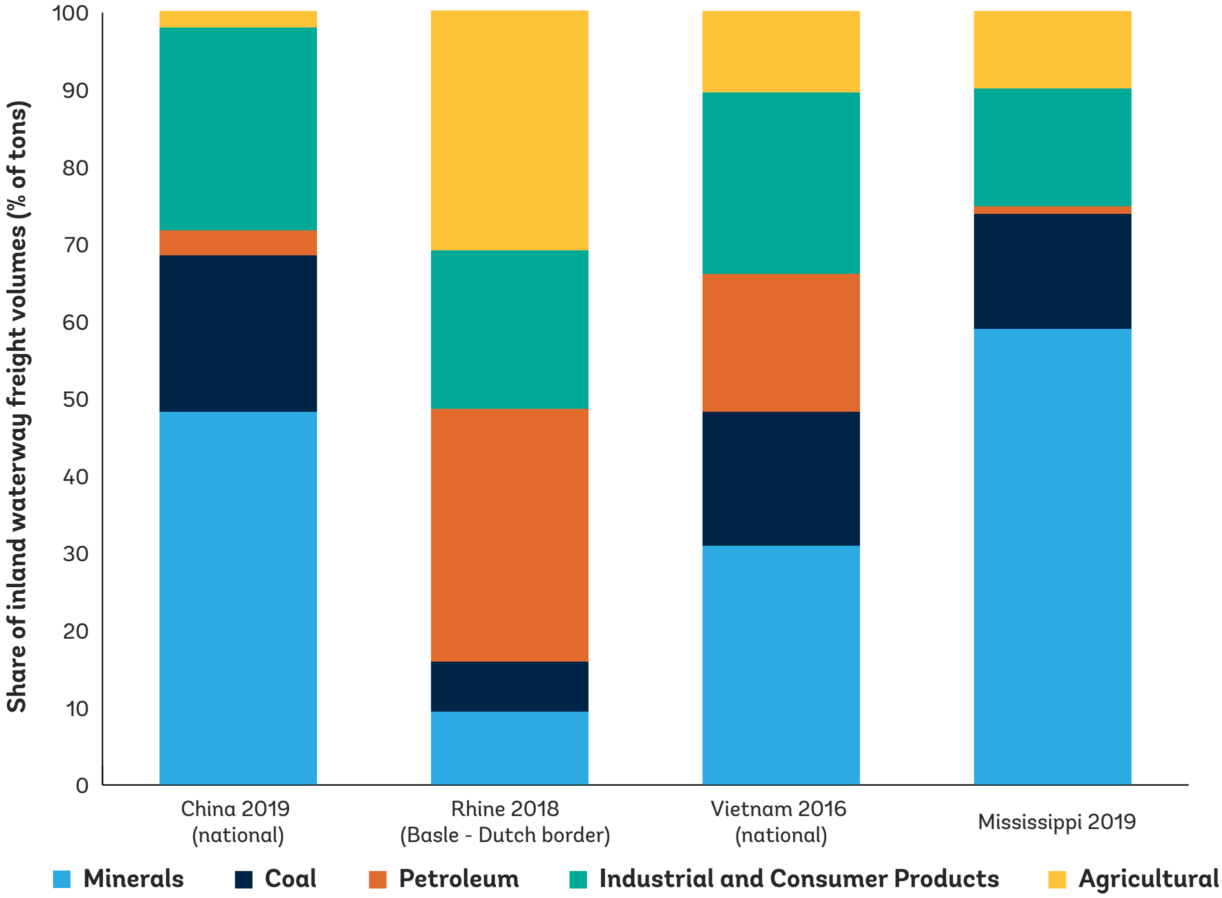
Figure 3.2. Rail Share of US Freight Traffic by Distance Carried



Source: World Bank analysis, based on data from US Department of Transportation, Bureau of Transportation Statistics (2015).

These influences can also be seen in the traffic mix on major inland waterway systems. IWT plays an important role in some countries of Europe (such as the Netherlands, Romania, Ukraine, and Russia), South-East Asia (such as Vietnam), China, South America (such as Argentina, Brazil, Paraguay, and Uruguay), and the US. Most IWT traffic is bulk and semi-bulk traffic (figure 3.3). However, containerized IWT traffic is growing globally. In Shanghai, for example, 47 percent of the port's inbound and outbound freight moved by water in 2019. Nearly 40 percent of containers at Rotterdam and over 30 percent at nearby Antwerp moved by IWT. The containers move both to local off-port terminals as well as longer-distance terminals of up to 900 km on the Rhine and 1500 km on the Yangtze.

Figure 3.3. **IWT Traffic by Commodity**

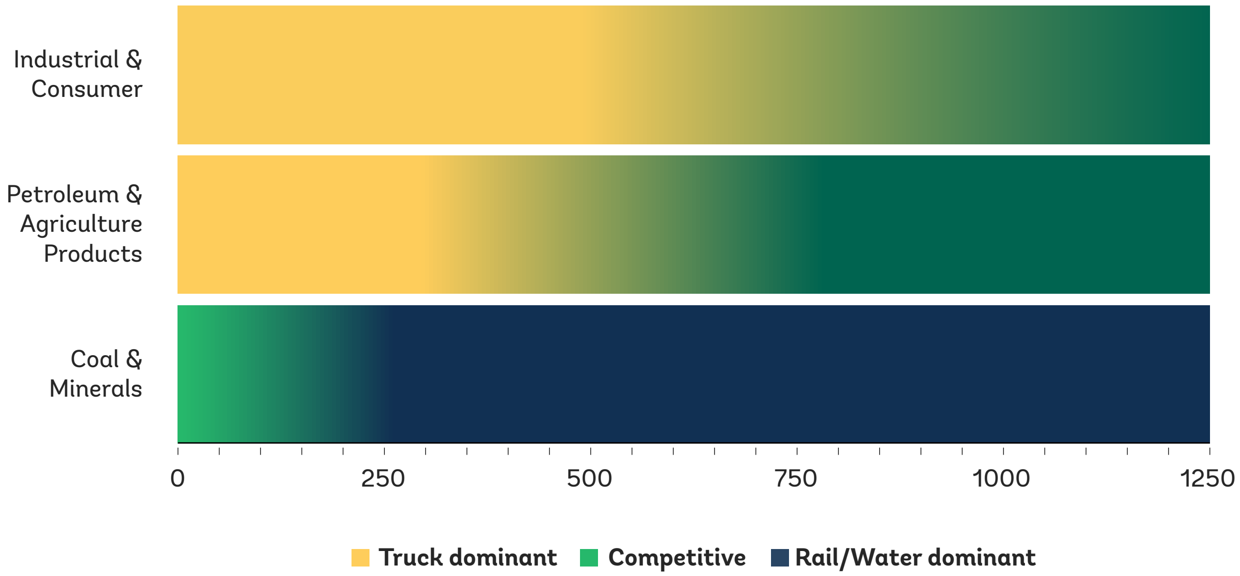


Sources: National Bureau of Statistics of China (2020); US Bureau of Transportation Statistics (2019); Central Commission for the Navigation of the Rhine (2019); and Hoang et al. (2019).

When considering mode shift from road to rail, traffic flows can be categorized into three broad groups: (1) rail dominant, (2) rail competitive, and (3) truck dominant. Coal, minerals, and construction materials are rail dominant over all except very short distances. Semi-bulk (petroleum and agricultural products) are generally truck dominant at short distances and rail competitive at medium and long distances. Industrial and consumer products would be truck dominant[11] at short and medium distances and competitive at long distances (figure 3.4). Yet, international experience often shows little alignment between the competitiveness profiled in figure 3.4 and actual modal choice because of constraints in non-road infrastructure and services. For example, in many countries, the bulk cargo is transported over medium-to-long distances by truck. Such situations point to opportunities for a modal shift.

[11] A large share of road traffic moves short distances, where modal shift is unlikely. In the US and EU, for example, 30-40 percent of ntkm move less than 300 km.

Figure 3.4. Competitiveness of Rail and Truck Modes



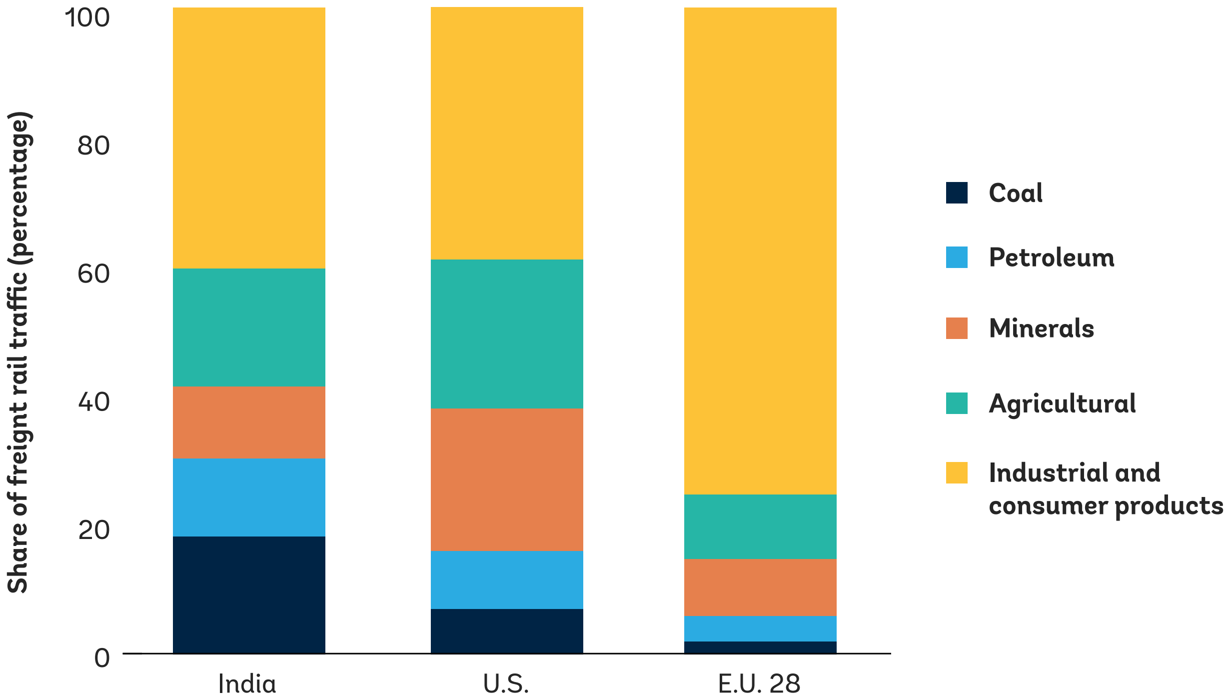
Source: Original figure produced for this publication.

International experience shows that realizing modal shift is difficult in practice and policymakers should set expectations accordingly. In potentially competitive market segments, rail transport can be expected to attract only part of the traffic. In the US market for import/export goods from the major California port to destinations east of the Rocky Mountains (distances of 1500 km or more), rail carries about 70 percent of the traffic. On the US East Coast, where distances to destination are shorter, rail carries 15-30 percent of the traffic. In most countries, where port hinterlands are much closer than in the US, 30 percent of port traffic moving by rail would be considered a good result (Lawrence and Bullock 2022).

Even longer distances and larger consignment sizes would be needed for IWT to be competitive with trucks. This is because IWT is slower and has larger consignment size than most freight railways.

A realistic mode split among rail, water, and truck differs substantially across countries because of the different types of freight activities and varying geographies. Figure 3.5 shows representative figures for three economic regions: United States, the European Union, and India. The EU transports primarily industrial and manufactured products—the hardest categories to shift—and relatively little of the dry bulk products like coal and minerals that are typically carried by rail and water transport. By contrast, the US and India transport a higher proportion of dry bulk and semi-bulk such as agricultural and petroleum products than the EU. Therefore, the potential for rail/water movement is greater in those countries.

Figure 3.5. Freight Traffic Mix by Commodity Group (based on ntkm) for India, US, and EU



Sources: India Planning Commission (2014); US Department of Transportation, Bureau of Transportation Statistics (2015); and Eurostat (2019).

Note: For movements > 50 km, shares measured in ntkm. All sources have different methodologies, the US survey is based on shippers and thus excludes own-account movement, which tends to be largely short distance moves such as agricultural products to storages and urban delivery. The EU survey is based on vehicles and the India data was based on roadside interviews focussing on inter-regional travel, typically trips of 75 km or more. As with all such surveys, the compatibility between different agencies varies both in terms of coverage and definitions but they still provide a reasonable picture at a summary level.

Determining a specific country's potential for modal shift requires analyzing the freight traffic the country generates by commodity and distance and then mapping that traffic to the country's transport infrastructure to see what modal shift opportunities exist. This analysis can help segment the freight market into rail/water dominant traffic, truck dominant traffic, and competitive traffic, with the easiest traffic to shift being long haul bulk and the most difficult being short- or medium-distance containerized traffic. Unfortunately, this foundational analysis is often skipped, perhaps due to difficulties in collecting and analyzing the data. Countries that have done the analysis find it can underpin their overall logistics planning as well as help identify modal shift opportunities.[12]

If a railway line or a navigable river is available to serve the rail/water dominant traffic, but is not moving it, potential exists for improving the service and shifting most or all the traffic to rail/water. Making the investments in rail and inland waterway freight transport infrastructure and services where these modes are dominant or competitive are real opportunities to improve the efficient flow of goods, encourage economic development, and reduce carbon emissions from the freight sector.

[12] World Bank has supported countries in Central and South Asia and Africa with this freight flow demand analysis and modeling.

3.2. Encouraging Modal Shift to Low-GHG Modes

Encouraging modal shift typically requires a combination of measures to discourage consumption of fossil fuels with measures to improve the service of low GHG-emitting modes of transport. Measures may include carbon pricing mechanisms (see Chapter 2), establishing balanced regulation between modes, developing the infrastructure of rail and water, improving the services provided by rail and water, integrating transport modes to encourage multimodal transport, and facilitating the process of assembling multimodal itineraries. A more detailed discussion of these measures for rail can be found in Lawrence and Bullock (2022).

Balanced regulation removes incentives that encourage use of trucks rather than greener modes. In some countries, rail and/or water users (usually the freight users) are charged most or all the cost of providing the rail or inland water infrastructure while the government provides support for building roads and highways for which cost recovery through fuel taxes and tolls is modest. Rebalancing the cost recovery either by increasing cost recovery from road users or providing additional support to rail and IWT infrastructure, as is done now in many European countries, would "level the playing field" for all and reduce the incentives to use trucks. Similarly, external costs—GHG emissions, noise, congestion, and crashes—can be measured, costed, and taxed to the entities generating them.

Supporting railway and waterway infrastructure development in appropriate markets provides alternatives to truck-based transport. Often, infrastructure is inadequate or not in the right place. For example, in Sub-Saharan Africa, the rail network density is 30–50 km per million people (compared to 200–1000 km per million people in Europe); furthermore, as many as 13 countries have no rail network, despite African exports being "largely bulky primary commodities that can be moved more efficiently and at lower costs through rail than road transport" (African Development Bank 2010). Where analysis shows rail or IWT can offer competitive service and lower cost (and, for water, a potentially navigable waterway exists), governments should support investment in creating or upgrading infrastructure (box 3.1). In lower-density markets, governments will also need to provide support for maintenance of infrastructure, as it does for roads.

Box 3.1. Dedicated Freight Corridor in India

The Government of India supports the Dedicated Freight Corridor Corporation of India, Ltd. to build new, high-capacity dedicated freight corridors (DFCs) parallel to existing mixed-use, and heavily congested, lines. The construction of these DFCs is part of India's nationally determined contributions under the Paris Climate Agreement and is intended to provide high-quality rail freight transport that will attract freight traffic to rail from road. The initiation of a truck-on-train service on one of the newly opened sections loads trucks onto rail flat wagons for transport by rail. The service, which can handle 300 trucks per day, delivers the trucks in 10 hours, compared to 24 to 36 hours by road. In the first 11 months of operation, the service saved an estimated 1.1 million liters of diesel fuel and over 3,000 tons of GHG emissions.

Source: Dedicated Freight Corridor Corporation of India, Ltd.

Developing logistics facilities that connect rail and waterways with ports and roads efficiently will enable multimodal transport that uses rail/water transport for the linehaul and road transport for the final delivery. The link between multimodal logistics clusters and increasing or sustaining high barge/rail modal share can be seen in countries such as the Netherlands and the US, where they facilitate multimodal transport. A study of modal shift in the Netherlands and Belgium found that short haulage distance for the truck leg of the journey was important for a modal shift, thus "a dense network of terminals located at strategic locations is important…for the possibility for organizing more sustainable transport via barge…" (Meers and Macharis 2015). Modeling of the US freight network demonstrated investments in key multimodal terminals would yield welfare benefits from a modal shift to rail and rebalancing of economic activity to areas with low trade costs. While most logistics facilities are developed by the private sector, some countries require new logistics facilities to provide rail and waterway connections as well as road connections whenever that is practicable.

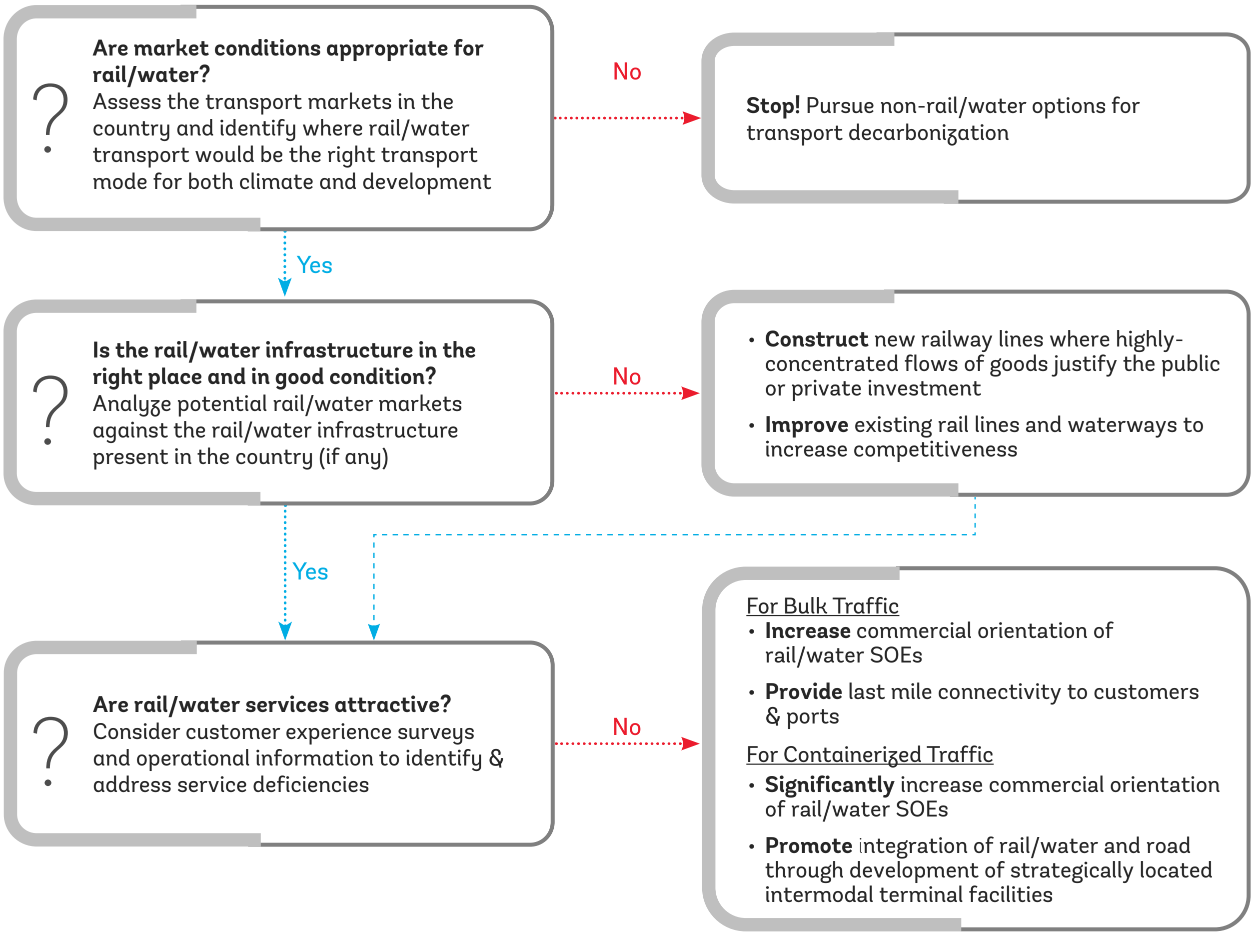
Serviceable infrastructure needs to be combined with customer-responsive service offerings. When rail and waterway services are provided by state-owned enterprises (SOEs), these entities must be managed commercially to be able to compete effectively with trucks, which normally operate in the private sector. When the traffic to be shifted is containerized, a fundamental shift in the commercial orientation of the SOE is required, along with the development of a 3PL industry to manage the retail portion of the value chain and development of logistics facilities.

Image 3.3. Cranes Transfer Freight to Trains and Barges

Source: Adobe Stock

Figure 3.6 outlines the series of questions and related policies that countries can use for encouraging modal shift. The development of a modal shift policy starts with analysis of the country's freight markets to determine if market conditions are suited to transport by rail or waterway. If suited, the demands are matched to available infrastructure and the gaps addressed. Services are also examined for their responsiveness to customer needs, with different measures to improve services for different types of traffic.

Figure 3.6. Key Questions and Policies for Modal Shift



Source: Original figure produced for this publication.

4 Increasing Efficiency of Vehicles, Facilities, and Operations

Key Messages

- **At the operational and technical level, improvements in logistics efficiency have direct and proportional impacts on reducing GHG emissions. Logistics service providers often already adopt measures to improve the efficiency of their vehicles, facilities, and operations because these measures also reduce operating costs.**
- **While most efficiency measures have a modest individual impact, over time, they result in a steady improvement in energy efficiency.**
- **Impacts from improvements in vehicle energy efficiency often take time to emerge at a fleet level, as many vehicles are replaced over a life of 20+ years. This is particularly true for truck fleets in LMICs, which are often imported second-hand.**

For freight transport, the energy intensity of a given mode is largely determined by the technical efficiency of the vehicles, their engines, and capacity utilization. Technical (or energy) efficiency of vehicles is often measured in terms of the liters of fuel or kilowatt hours (kWh) of energy consumed per unit of work (for example, 100 km traveled for road vehicles or 1,000 gross ton kilometers (gtkm) for rail). Various technical, operational, and behavioral measures exist to improve the technical and operational efficiencies of different freight vehicles. These measures are mutually supportive and, in many cases, implementable in the short to medium term.

Most efficiency improvements are incremental and will be introduced over 20 years or more as the fleet is renewed and operating practices change. This has been evidenced across all freight modes over the past decades. Aviation, rail, maritime shipping, and trucking have all seen gradual improvements in efficiency. For example, aviation fuel efficiency improved by 40 percent between 1970 and 2018 (about 1.1 percent per annum) (Malina et al. 2022). Fuel efficiency in the international shipping industry improved from 15.2 gCO_2e/ntkm in 2008 to 10.7 gCO_2e/ntkm in 2018—a nearly 30 percent decrease in 10 years (International Maritime Organization 2021). Efficiency improvements in road and rail freight transport vary significantly by country, but data from the US suggests that the freight fuel efficiency of Class 1 railroads in the US (measured in kJ/ntkm) improved by over 50 percent between 1975 and 2018 (Association of American Railroads). These results are the realized benefits of multiple approaches for improving fuel efficiency. Thus, although an individual initiative might generate savings of 2–5 percent of fuel, the observed impact, which will be combined with many other initiatives, will probably be a continuing improvement of 0.5–1 percent per year in overall efficiency, which is difficult to ascribe to any one initiative.

4.1. Vehicle Efficiency

Transport managers have been concerned with the efficiency of their fleets for as long as engines have burned fuel. Greater vehicle, vessel, or plane efficiency means that operators can transport goods over a given distance with less fuel. Since fuel is often a major component of freight transport costs, using less fuel means lower costs. For fossil fuels, using less fuel also means lower GHG emissions, since GHG emissions from any fossil fuel are directly proportional to the volume of fuel consumed.

Across modes, two basic approaches exist to improving fuel efficiency:

- improving the technology that converts the fuel/energy into the ability to do work (for example, more efficient diesel engines), typically achieved through fleet or engine renewal
- reducing the work required to perform a given task, typically achieved by retrofitting the current fleet (for example, to improve aerodynamics)

Road

Road transport covers a diverse range of activities, from local deliveries made with light commercial vehicles (LCV) to long-distance transport in vehicles with gross weight as much as 50 tons. Given the disparity in task and gross vehicle weight, the emissions also vary widely, from around 90 gCO_2e per ntkm of goods for medium and heavy trucks to about 400 gCO_2e per ntkm for LCVs.

Improving the fuel efficiency of truck fleets is a slow process, particularly in LMICs. In many LMICs, trucks—like many passenger vehicles—are imported second-hand and may already be over 10 years old before entering operations in the country (World Bank 2021; UN Environment Programme 2019; 2020). This introduces a significant lag between new, more fuel-efficient technology being introduced by vehicle manufacturers and the vehicle technology being sold in LMICs.

Comprehensive fleet management programs from the point of sale through on-road use to end-of-life can help shorten the cycle of vehicle renewal (Gorham et al. 2022). Such a program could include:

- vehicle emissions standards applied when vehicles are sold or registered that account for GHG emissions and/or local air pollutant emissions
- vehicle inspection systems that check for the proper functioning of vehicle emissions control technologies
- vehicle scrappage programs that incentivize the retirement of the oldest and most polluting vehicles

As operating margins are often very low, governments can encourage fleet renewal by expanding access to financing and addressing the business model and operating structure of the typically fragmented trucking industries of many LMICs. The lack of profitability of both managed fleets and individual owner-operators often leads to poor maintenance of vehicles and their engines—increasing emissions—and does not leave room for saving toward a new vehicle or for collateral against a loan with a competitive rate.

While a complete turnover of the freight vehicle fleet can take decades, there is a broad range of opportunities for improving the fuel efficiency of on-road vehicles that are already in use. Such improvements normally require additional investments, but road transport operators are likely to make such investments if they pay for themselves within a few years from fuel cost savings. Other potential improvements may have longer payback periods or may not yet have a commercial case under current policy settings. Governments will need to either regulate their introduction, provide direct financial support, or change the policy and pricing environment to incentivize their adoption.

A wide range of technology improvements have either been proposed or are under development, with the most promising being: vehicle light weighting, aerodynamic fittings to tractors and trailers to reduce drag, improved tires, improved drivetrain and auxiliary equipment, and engine controls (Teter, Cazzola and Gül 2017; Delgado et al. 2016).

- Light weighting to reduce the gross weight of the vehicle while retaining functionality. Weight reductions for road vehicles can be realized by materials substitution, particularly for the chassis and vehicle body. The reduction in vehicle weight enables the truck to carry more goods while remaining within axle load limits. Such higher capacity vehicles have improved fuel efficiency and reduced GHG emissions compared to traditional trucks.[13] One forecast of truck light weighting estimated a 7 percent reduction in vehicle tare weight from 2015 to 2025 and GHG reductions of up to 5 percent per truck by 2050 (Ricardo-AEA 2015).
- Aerodynamic fittings to reduce drag. Drag typically accounts for up to 20 percent of fuel consumption for trucks traveling at 70–80 km/hr (and more at 100 km/hr) but only around 5 percent for typical urban operations. Drag occurs not only from the front of the vehicle but also from the side and end profiles and there are, thus, a large variety of possible aerodynamic fittings that can reduce it (figure 4.1). These have already been widely adopted in many countries and are reported to reduce fuel use by 0.5–3 percent, depending on the precise circumstances.
- Tires with low rolling resistance and optimized tire pressure systems. Tire resistance accounts for 7 percent of fuel consumption for rigid vehicles and around 15 percent for articulated vehicles. Low rolling resistance tires can reduce tire resistance by 10–30 percent or more (Meszler et al. 2018) and automatic tire pressure adjustment systems can also help. Overall, they are likely to lower fuel consumption by an estimated 0.5 percent to as much as 5 percent, depending on the type of truck.

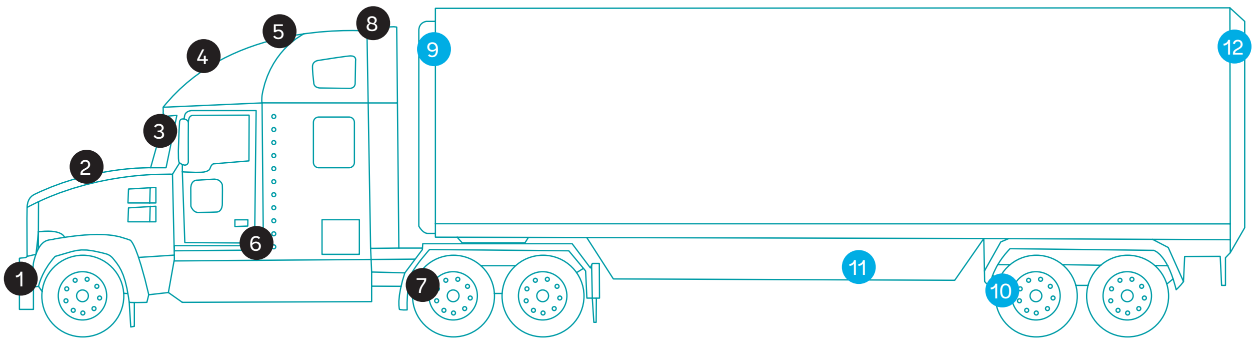
Image 4.1. A Truck on the National Highway Heading toward Burkina Faso

Source: Amuzujoe (2019).

[13] For example, the so-called 'Canadian B-double', which has two trailers and a maximum GVW of about 60 tons, is heavily-used in Australia, where it has been operating for over 30 years. They operate on specified routes and generate emissions per ntkm that are about 20 percent lower than a conventional six-axle articulated vehicle (Australian Trucking Association Ltd. 2018).

Figure 4.1. Types of Aerodynamic Fittings for Tractors and Trailers that Can Help Reduce Drag, Fuel Consumption, and GHG Emissions from Trucks

Tractor Strategies	Trailer Strategies
1. Aero Bumper	9. Tractor Mounted Gap Reducers
2. Aero Profile Tractor	10. Low Rolling Resistance Tires
3. Aero Mirror	11. Trailer Side Fairings
4. Integrated Cab Roof Faining	12. Trailer Rear Fairings or Boat Tail
5. Idle Reduction Equipment	
6. Fuel-Tank Side Fairings	
7. Low Rolling Resistance Tires	
8. Trailer Mounted Gap Reducers	



Source: Original figure produced for this publication.

- The drivetrain and auxiliary equipment (pumps, fans, HVAC) typically account for about 5 percent of truck fuel consumption. Adopting automatic transmissions can reduce fuel consumption by up to 2 percent. The auxiliaries can be decoupled when not in use and otherwise optimized while friction within the transmission, shaft, differentials, and axles can also be reduced via improved in-gear efficiency, lubricants, and bearings, potentially saving a further 0.5–2.5 percent.
- The engine itself accounts for 60–70 percent of energy consumption in a truck. For diesel engines, manufacturers have introduced improvements to engine efficiency such as enhanced injection and cylinder pressures, better fuel automatization and in-cylinder distribution, increased compression ratios, improved thermal insulation, and sophisticated engine controls. A potential longer-term development is to recover the energy lost to exhaust gases and improve engine cooling, which can result in possible energy savings of 3–6 percent.

Fuel consumption is directly related to the quality of the road infrastructure. Many studies have shown that fuel consumption increases as road roughness increases. For a paved road, there can be a 2–5 percent difference in fuel consumption between a good quality road and a poor condition road; comparing a gravel road to a good quality, sealed road, the difference can be as much as 10–20 percent of fuel consumption. However, in practice, some of these gains may be eroded because of the higher speeds at which vehicles often travel on better-quality roads.

Eco-driver training and devices that monitor fuel efficiency have been shown to reduce truck fuel consumption by up to 5–10 percent, especially when combined with driver rewards and bonus schemes to reinforce learned behaviors beyond the training period (for example, Wang and Boggio-Marzet

2018; AECOM 2016). Many of these programs focus on reducing idling and techniques for more gentle acceleration and deceleration. They have demonstrated significant GHG emissions savings (at very low cost) in China, Thailand, Lao People's Democratic Republic, and Vietnam (ADB 2016; Grütter and Dang 2016). The GHG emissions-reduction potential of eco-driving training is potentially greater in LMICs than HICs because of more difficult traffic conditions and the older truck fleets not being equipped with onboard driver assistance devices. Incentives are particularly well aligned in countries where drivers are responsible for their own fuel costs. Driver training can also improve road safety, an important co-benefit in LMICs with high traffic fatalities and injuries.

Experience in the Philippines and elsewhere shows that embedding fuel-efficient practices generally requires electronic monitoring of subsequent driving performance and follow-up guidance where necessary (Abuzo and Muromachi 2014). The longer-term effectiveness of the training as a cost- and carbon-saving measure depends on carriers having the resources to equip their vehicles with these monitoring systems (Boodlal and Chiang 2014). Technological advancement could further enhance gains from eco-driving. One possible development is platooning, in which trucks that closely follow each other are equipped with 'smart' vehicle communication and automation (connected autonomous vehicle) technologies. With such an arrangement, trucks could drive closer together at near-constant speeds, while reducing air resistance. Fuel savings of 5–15 percent have been estimated for a three-truck platoon traveling at 80 km/h, depending on the gap between vehicles (Lammert et al 2014).

Fuel efficiency of road freight has steadily improved. For example, in the US, road freight fuel efficiency has increased by 1–1.5 percent per year for decades. This has largely been driven by operators acting out of self-interest and adopting measures to improve efficiency to save fuel costs. While fuel efficiency improvements of engines burning fossil fuels, when taken together, add up to measurable GHG savings (box 4.1), a transition to alternative fuel vehicle and engine technologies will be needed to achieve major reductions in GHG emissions. Yet, given the gradual nature of the alternative fuel vehicle transition, fuel efficiency improvements in diesel engines will need to continue for years to come.

Box 4.1. Guangdong, China: Green Freight Transport Project

The *Guangdong Green Freight Project* was a comprehensive initiative with the goal to tackle carbon emissions and improve energy efficiency in the freight transportation sector in Guangdong Province, China. The primary objective was to encourage the use of clean energy, optimize transportation routes, and implement smart logistics technologies in a bid to decrease fuel consumption and GHG emissions.

The outcome of the project revealed that in the case of green truck technology, readily available and proven technologies like aerodynamic fittings (such as roof fairings), low resistance tires, or driving behavior diagnostic and operation monitoring systems can all significantly contribute to the reduction of GHG emissions.

The post-project analysis demonstrated that the implementation of these eco-friendly measures was financially feasible for the participating trucking companies and lowered CO_2 emissions per truck (depending on the truck and the measures adopted) by up to 4 percent.

Source: World Bank Group 2016.

Rail

Interventions that improve rail fuel efficiency can be categorized as technological, infrastructure, and operations. Technological improvements to improve energy efficiency include improvements to locomotives and brakes; infrastructure improvements including better track maintenance; and operational improvements range from improved driving techniques to better service management.

Both diesel and electric locomotives have seen substantial improvement in energy efficiency in the past 20 years. Electric locomotives have an overall energy efficiency of typically 80 percent to 85 percent. A diesel locomotive also needs to allow for the efficiency of the diesel engine itself (typically around 40 percent) giving an overall efficiency of about 35 percent. Both types of locomotives need to provide power to auxiliary systems other than the engine itself and have losses of the same order of magnitude in the intermediate processes. The introduction of traction motors fed by alternating current (AC) rather than direct current (DC) has significantly improved energy efficiency over the last 20 years.[14] While further advances can continue to be made in engine technology, the current level of energy efficiency is such that further gains are unlikely to be more than a few percent (Lawrence and Bullock 2022).

Rail freight wagons have also achieved light weighting to improve energy efficiency. Railways have demonstrated improvement in the ratio of vehicle weight to load over time. At a rail system level, the overall ratio of gtkm to ntkm (tare+net: net) provides a good indicator of energy efficiency. However, in comparing these ratios across rail systems, a difference of 5–10 percent may be found because some railways include the weight of the locomotive in the tare weight, while others do not.

When a train brakes, it generates energy that can sometimes be recovered through what is known as the "dynamic brake." On electrified railways, the braking energy can be returned to the railway power supply (a process known as regeneration) or stored either on-board or off-rail in an energy storage system. In practice, regenerated electricity is rarely accepted back to the grid due to its poor quality and the typical recovery rate for freight services is up to 5 percent. Locomotives with this capability have been available for several years and regeneration should be considered wherever lines are electrified and there is enough traffic to take advantage of the regenerated energy.

Better quality infrastructure will reduce fuel consumption. Maintaining track quality helps minimize fuel consumption by reducing the friction between wheel and track and through reducing kinetic energy lost due to impacts and vibration. It also reduces the frequency and duration of temporary speed restrictions due to poor maintenance or grade crossings, which cause the train to decelerate and accelerate more often, hurting fuel efficiency. Improving track quality by upgrading track standards such as easing of small-radius curves and limiting grades in hilly sections also saves energy.

[14] This is independent of whether the main current feed is AC or DC.

Operational improvements range from driving techniques to management emphasis on energy, including:

- Improved driving techniques: On-board monitoring and advice systems have been developed to optimize engine use by providing acceleration control and optimization of driving behavior (Niu et al. 2020; Yee, Coleman and Wardrop 2007).[15] Systems that provide advance warning of possible delays, allow speeds (and hence fuel consumption) to be adjusted. France has achieved savings of around 7 percent in trials with TGV and, in Germany, measures of this type have reduced energy consumption on an intercity express route by nearly 5 percent.

- Reducing aerodynamic drag. As speed increases, aerodynamic drag on both the front and the sides of a train becomes an increasingly important component of resistance and this can be reduced by greater attention to streamlining. This is affected by wagon positioning and railways should be encouraged to ensure both train assembly and the freight wagons themselves are designed to minimize wind resistance (Krishna, Stichel and Nia 2018; Baker 2014; Turner 2013; Moynan 1999).

- Management also has a significant role to play, from training staff to practice energy awareness to installing comprehensive systems to monitor energy consumption. Monitoring fuel and energy consumption is now increasingly possible on a train-by-train basis and this by itself has enabled savings of 5 percent or more.

This focus on saving energy needs to be reinforced regularly and requires commitment at the Board level to ensure GHG emissions are minimized. Regular, detailed reporting with a sound energy consumption index and monitoring of locomotive fuel and power consumption is needed.

Maritime (and Coastal) Shipping

Over the past decades, the hydrodynamic efficiency of ships has been improved significantly. Traveling at the same speed, new ships have a 20 to 25 percent lower power demand than ships built in the 1960s and 1970s. The improvement is 10 percent compared to ships from the 1980s. Further vessel design measures that have been developed and are being implemented should continue to improve fuel efficiency, mostly by reducing hull resistance. Some improvements relate to the initial design of the ship and will only apply to new-builds, but others are comparatively low-cost and can be applied to existing vessels. For example, several modifications enhance the efficiency of propellers that can be readily retrofit onto operating ships.

The marine diesel engines themselves already operate with a high level of efficiency and future efficiency gains are likely to be small. Around 10 percent of the world fleet is already fitted with more efficient electronically controlled engines, representing around 41 percent of the total deadweight capacity (Clarkson Research Ltd. 2022). There are technical proposals for wind-assisted ship propulsion through the use of sails and Flettner rotors, for example. However, to date, these have not been adopted at scale. Additional technical efficiency gains are also possible from air lubrication to reduce the resistance between the ship's hull and seawater. Further improvements of the hull and propeller design and maintenance are possible. Onshore (renewable energy) power can also be supplied to ships when in port. This eliminates their need to run the engines to produce energy while at berth (box 4.2).

[15] Examples of technologies developed to improve driving techniques to reduce fuel consumption and associated emissions include: GE Transportation's Trip Optimizer™, New York Air Brake's Locomotive Engineer Assist/Display and Event Recorder (LEADER®), and Progress Rail/EMD's SmartConsist™ (Stagl 2017).

Box 4.2. Onshore Power Supply to Ships in Ports

Ports play an important role in reducing GHG emissions from shipping, as approximately 5 percent of the total GHG emissions generated by ships are generated in ports. An effective measure that ports can implement to reduce emissions is the supply of electric power to ships while they are berthed. Connecting ships to the electricity grid via onshore power supply (OPS) facilities in ports can significantly reduce air and noise pollution, reducing local emissions. The use of carbon neutral electricity can further amplify the reduction in GHG emissions. However, the installation of OPS infrastructure at ports and the adaptation of ships may be costly. To make OPS more attractive, financial incentives such as energy tax exemptions or port fee reductions can be offered. OPS is already mandatory in certain regions and is expected to become more widespread in the coming years.

Sources: ITF 2018; Global Maritime Energy Efficiency Partnership (GloMEEP).

The operational measure with the largest impact on GHG emissions is reducing the ship's speed. Power demand and fuel consumption rise non-linearly with speed. Accepting more sailing time compared to the minimum time attainable at full throttle allows for significant reductions in fuel consumption. Even when maintaining the same sailing time between origin and destination, many stretches allow significant fuel savings by means of 'smart steaming'—the optimized choice of route and speed according to the local waterway conditions. Smooth steering with minimized rudder activity helps to increase the speed with a given power. Such smart steaming is being facilitated by tools such as Opt-e-Arrive in Singapore, which allows better planning and optimization of ship speeds by coordinating arrival times in ports based on berth availability (Taylor 2022). Optimized weather routing is also possible.

Inland Waterway Transport

Although IWT is an energy-efficient form of transport, opportunities to improve fuel efficiency still exist. The four regions with the most significant IWT operations—United States, China, Rhine/Danube, and the Amazon Basin—have different operating conditions in terms of length of haul, maximum draft, and type of vessel. Therefore, only some of the options in this section will apply to any one of them, but the general principles are also applicable in countries where IWT (including lake transport) is smaller, but still significant locally.

A fundamental requirement is for the IWT infrastructure to be properly maintained and bottlenecks addressed. One of the most basic measures that supports energy-efficient operations is to ensure water depths are maintained throughout the length of the system. Just a short stretch where the depth has reduced will limit the size of vessels operating along the entire length of the waterway. This also applies to locks. Attracting more traffic requires IWT to demonstrate it can provide reliable and punctual service. On many IWT networks, locks are a key feature. They need to be maintained so that they can handle standard vessels and barge-trains without physical difficulties, and they need to be operated efficiently so that vessels are not delayed, and congestion develops. As with maritime shipping, the energy demand can be reduced through slow and smart steaming, with reduced waiting times at locks and efficient integration of IWT in seaports. Providing real-time data on the conditions in the waterway and traffic flow information can increase energy-efficient navigation.

IWT terminals may need to be upgraded to increase efficiency. This is also true at ports, where IWT needs to be able to provide competitive feeder services to road transport. Improvements could include OPS to reduce diesel operations in terminals, as well as degassing facilities for petroleum and chemical tankers so that residues are not vented directly into the atmosphere.

Aviation

Aviation has seen a steady improvement in fuel efficiency over the last 30 years due to a combination of technological improvements to aircraft and engines, operations, and air traffic management (ATM). Improvements to energy efficiency in aviation include the use of lightweight materials, improved aerodynamics, and increased engine efficiency.[16] Aircraft technology determines the weight and the aerodynamics, which, in turn, are important drivers of fuel efficiency. Engine technology affects fuel efficiency through the thermodynamic efficiency and propulsive efficiency of the engine system (the product of the two being, 'overall efficiency'). The overall engine efficiency of new aircraft has increased from about 30 percent in the mid-1970s to the current 40 percent—or 0.6 percent per year (NAS 2016) and fuel per tkm in 2019 is about 40 percent less than in 1970. The use of lightweight composite materials such as carbon-fiber reinforced plastic has increased in the last 30 years.

Several studies have analyzed the potential for fuel efficiency improvements from technological advances related to aircraft weight, aerodynamic drag, and engine efficiency, with estimates of up to 50 percent, mostly from possible airframe developments (IATA 2019; Kharina, Rutherford and Zeinali 2016). However, the lead times required for the development and implementation of these advancements can be significant, as many require changes throughout the air transport system as well as their commercial acceptance by operators. Significant decarbonization potential through technological measures exists but the short- and medium-term impacts are constrained by the long fleet turnover times of 20+ years. Additional research and development efforts are still required for the more radical design and propulsion concepts.

As an immediate measure, cargo airlines looking to cut emissions can replace older aircraft with more efficient models. Cargo operators typically employ older planes as they are cheaper. Coupled with the usage pattern of cargo planes, which makes their life span longer than passenger planes, their overall emissions are usually higher. Estimates show that up to 20 percent emission reduction could be achieved by modernizing air cargo planes (Jeffrey 2022).

Aviation operations include the actual flying of the aircraft (airline operations), the control and monitoring of the aircraft by ATM, as well as operational activities at the airport (ground operations). Potential CO_2 savings from operational measures (such as fixed electrical ground power units, single engine taxiing, aircraft queue management, controlled pushback and optimized flight paths, speeds, and cruise levels) were estimated at 9 to 13 percent in 2010 (Kar, Bonnefoy and Hansman 2010). A more recent estimate, for ATM operations alone, pegged the fuel efficiency potential of more flexible routing and optimized flow management at 5 to 9 percent (Energy Transitions Commission 2018). Operational improvements have much shorter development and diffusion times than many technological improvements—and can therefore be implemented at scale in the short- and

[16] Energy efficiency in aviation can be approximated by fuel efficiency or the mass of fuel required to produce a unit of output. Common metrics are the mass of fuel per tkm, or the mass of fuel per passenger-kilometer (pkm). These are also affected by the seating density in an airplane and its load factor.

medium-term (Hileman et al. 2013). Current examples include the U. S. NextGen (Post 2021) and the E.U. Single European Sky Initiative (SESAR) (Motyka and Njoya 2020), which aim to increase airspace capacity, decrease congestion by minimizing detours, and optimize aircraft descents.

Opportunities exist for low-cost operational improvements at regional airports. A taxiway improvement project in Haiti saved about five minutes per aircraft turnaround with associated reductions in fuel consumption due to lower runway occupancy times and reduced taxiing distances. Another example is the Shangrao airport in China, which achieved 24 percent energy savings by leveraging energy-efficient architecture and airport layout design, ground aircraft auxiliary power units, energy-efficient equipment and infrastructure, stormwater reuse system, and ground source heat pump system. A new instrument landing system at St. Lucia reduced flight arrival delays, diversions to other airports, and cancellations during poor weather conditions, saving fuel as well as improving safety.

Logistics Facilities and Terminals

The principal energy uses in warehouses are lighting (up to 65 percent), heating, and air conditioning (for cold stores). Where possible, older sodium/metal halide lighting, and fluorescent tubes, should be replaced by LED lighting, as they can save over 50 percent of electricity. This can be combined with occupancy and ambient light sensors to avoid overlighting. Where there are large buildings with steady airflows, heating and cooling loads can be reduced by improving the insulation of the roofs and walls, while heat pumps (especially if ground-source) can be used to provide economical and efficient low-carbon heating and cooling. Warehouses normally have extensive roof areas that can support large areas of solar panels to generate power for its own use (Freis, Vohlidka and Günthner 2016).

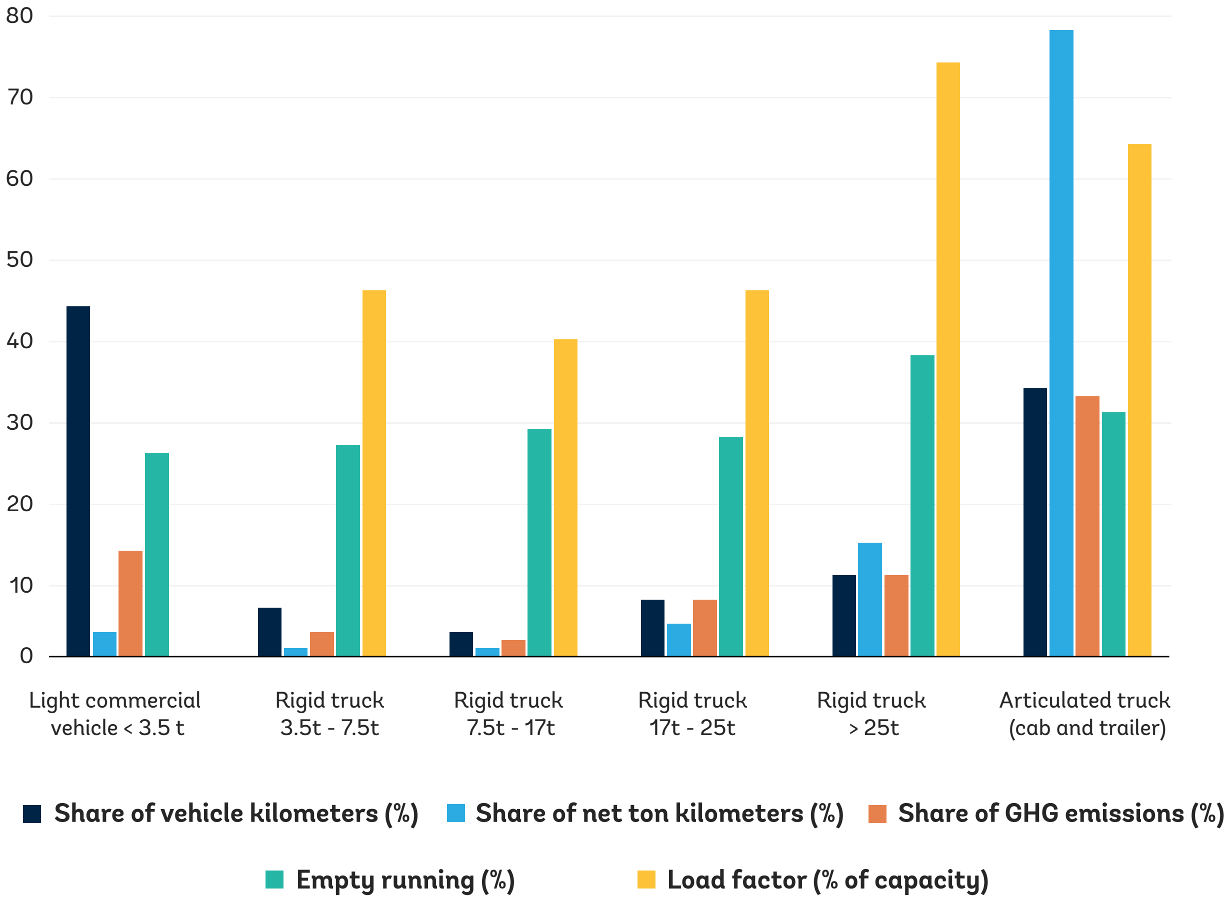
The other energy use in warehouses is for plant and equipment such as forklifts, almost all of which can be converted to electricity or other alternative fuels. Freight terminals are not major users of energy, at least on a per unit of throughput basis. Major container terminals such as Felixstowe in UK and the various ports operated by Singapore Ports Authority emit 6–13 kg CO_2e per twenty-four-foot equivalent unit ([TEU] container), while an estimated 20 kg CO_2e/TEU has been quoted for Chinese ports. About 60 percent, in the case of Singapore, was for diesel used by internal cranes, marine vessels, and internal road transport, while electricity was used for electric cranes and reefer points. Real opportunities exist for decarbonizing port operations, including transitioning cranes, rubber-tired gantries, and prime movers from diesel to electric (or hybrid), in combination with green electricity.

Guidance exists on possible measures for improving the energy efficiency of railway buildings, including logistics-related facilities (ADB 2015). Railways also use energy for infrastructure facilities, including signaling and points motors. In winter, the point motors need to be heated and some railways have automatic monitoring of temperatures at each location to control the quantity of heating. SBB in Switzerland, for example, has 7,400 point heaters automatically connected to temperature sensors to control heating, and similar systems cover all locations on the railway (SBB.ch 2018).

4.2. Efficient Vehicle Utilization

Considerable GHG emissions are generated when transport vehicles move empty or only partially loaded, so reducing empty transport could potentially enable the same amount of goods to be moved with less transport, saving GHG emissions. In the UK, for example, 25-35 percent of truck kilometers are empty (figure 4.2). The US has similar empty statistics, depending on the type of vehicle, with larger vehicles having higher rates of empty running (Terrazas 2019). EU data, which includes freight-carrying LCVs, gives somewhat lower figures, with empty running at 20 percent of total truck-km (Eurostat 2021). Railways also operate significant empty wagon-km.

Figure 4.2. UK Freight Vehicles Kilometers, Empty Running, and GHG Emissions, 2019



Sources: Based on data from UK Department for Transport (2023).

While these empty movements suggest potential for improvement, much of the perceived lack of utilization is an inevitable consequence of market forces and traffic patterns. Many major freight flows are unbalanced, with volumes much greater in one direction than in another because production of goods is in one area and consumption in another. Freight vehicles are often specific to a particular commodity or group of commodities, limiting the ability to reload them on the backhaul.[17] The volumetric capacity of freight vehicles is also subject to constraints in most countries. This means that many freight operations will never reach their nominal tonnage capacity.

[17] An obvious example is tankers, which are not only restricted to bulk liquids but also to specific types of liquid.

Even when loaded, many road vehicles do not carry their maximum payload. When freight is voluminous, vehicles can carry their maximum cubic capacity but not their maximum weight. Figure 4.2 shows that in the UK, the average load factors for different truck types range from 40–75 percent. This increases the fuel consumption significantly per ntkm. Analysis by the Global Fuel Economy Initiative shows an increase of 60 percent when a heavy freight vehicle is half-loaded compared to when it is fully loaded (Delgado et al. 2016). Rail wagons, likewise, often "cube out" before they reach their weight limits. In the US, for example, the average capacity of a US rail wagon in 2015 was over 100 tons but the average load per loaded wagon was only 55 tons. While bulk traffics such as coal averaged over 100 tons, others such as automobiles, paper products, and textiles averaged well under 50 tons.

While most decisions affecting vehicle utilization and loading will be made by the private sector, governments can encourage improvements in several ways. First, governments can eliminate outdated regulatory restrictions on vehicle dimensions and operations, balancing the potential roadway wear and tear and road safety challenges that come with bigger or more heavily loaded trucks. Second, governments can encourage the development of online platforms for finding loads and the use of computerized route planning and scheduling.

Inefficient regulation of the freight sector contributes to empty running and underloading in some countries. Rules limit freight to certain groups of operators or prohibit operators from crossing state or national boundaries. Many countries have historically implemented arrangements with formal freight allocation procedures as well as limitations on backloading. Those operating in West and Central Africa are well known and have been extensively documented (Bove et al., 2018; Teravaninthorn and Raballand 2009). Such practices protect inefficient operators and restrict the introduction of more flexible management practices that can improve overall efficiency.

In India, an estimated 30-50 percent of trucks return empty after delivering cargo, partly because the industry consists of small, regional operators (Financial Express 2021) and regulatory barriers such as state trucking licenses that only allow the truck to operate within the licensing state. Thus, while truck operational efficiency is mostly the result of many decisions made by private truck operators, the government can review its regulations to ensure that market restrictions do not limit the ability of truckers to fill empty backhauls or unduly restrict firm size/industry consolidations.

A major development in road transport in the last two decades, helped by the widespread availability of mobile phones, has been the growth of online platforms for the buying and selling of vehicle capacity. Such platforms have been well established in high-income countries for 15+ years and are now growing rapidly in countries such as India, China, Indonesia, and Nigeria. Within six years, Freight Tigers, India's largest online freight platform, captured around 2–3 percent of all road freight transactions in this $110–130 billion market (see box 4.3). Where the trucking industry is fragmented, such as in India, these platforms allow truckers to find backhauls and minimize empty movements. They give details of available loads to any operator with a mobile phone as well as access to a range of other freight management services, including route planning, track-and-trace, proof of delivery, and invoicing. All of these can help improve capacity utilization, avoid wasteful transport, and reduce GHG emissions. Governments can encourage such developments and ensure there are no regulatory impediments to their adoption.

Box 4.3. Fuel Efficiency and Operational Improvements from Collaborative Digital Platforms: Examples of Rivigo and Freight Tiger in India

Trucking accounts for the largest share of India's logistics and freight transport emissions. Historically, long-haul trucking operations in India have been plagued by low efficiency because of fragmentation of operations and poor use of vehicle capacity, dispatching, and scheduling that contribute to frequent empty backhauls (Sahu, Pani and Santos 2022). Innovations in the private sector are improving trucking operations, which, in turn, reduces fuel consumption and related GHG emissions.

Rivigo is a major logistics provider in India, which has pioneered a relay model of logistics across a network of "pit-stops." The relay model separates a long-haul freight trip into smaller segments (of 4–8 hours), traveled by separate drivers. One of the main motivations of this operating model is to improve drivers' lifestyles by allowing them to return home every day. Rivigo's model also leverages digital technology to improve the efficiency of vehicle use by coordinating loads for both outbound and return trips by each driver and has an additional positive, although small, impact on fuel efficiency as drivers tend to gain greater special specialization of routes and quality of physical road infrastructure that improves their driving behavior and fuel consumption.

Freight Tiger provides a digital freight platform that improves visibility and control of trucking operations and real-time matching of trucking capacity (supply) with shipper demand. Over 4000 truck operators are registered and pre-vetted with the platform which allows shippers to spot-book loads in their vehicles, maximizing vehicle loading and therefore efficiency. The platform also provides driver training to further improve efficiency. Businesses that belong to the platform benefit from greater driver retention, higher asset utilization and reduction of empty backhaul trips, reduced transit time, and better fuel efficiency. By optimizing processes across the supply chain, Freight Tiger claims to have helped eliminate up to 220 million tons of CO_2 emissions since its launch in 2017 (2023).

Innovative applications of digital technology have the potential to drastically transform the dynamics of freight operations and significantly mitigate the resulting GHG emissions. Beyond India, other examples of these innovations include CargoX in Brazil, Huochebang and G7 in China, Kargo and Waresix in Indonesia, Ezyhaul in Malaysia, Kobo360 in Nigeria, and Tirport in Turkey.

Source: World Bank analysis based on Sahu, Pani and Santos 2022; and Freight Tiger 2023.

A more formal form of capacity sharing is co-loading, which bundles shipments with similar destinations and delivery times across different shippers. This requires considerable horizontal collaboration (often with competitor companies) and therefore has high barriers to general implementation by the private sector. Co-loading is expected to bring significant benefits to urban logistics applications (for example, Janjevic et al. 2018). The development of logistics clusters around manufacturing industries may enable "milk run" logistics, where one vehicle conducts several pick-ups/deliveries in a round trip. This model has the potential to increase vehicle utilization and therefore, reduce emissions.

A second transformative digital tool is computerized vehicle routing and scheduling (CVRS). More efficient routing, particularly on multiple collection and delivery rounds, can reduce the distances freight consignments travel between a given set of origins and destinations. As a substantial share of truck vehicle-kms are driven by LCV operators making multiple stops, LVCs could especially benefit from using CVRS systems.[18] Advanced CVRS systems can be set to minimize fuel consumption and CO_2 emissions even if this does not necessarily minimize vehicle-km or tkm. Governments should encourage the adoption of such tools, especially for those doing last-mile deliveries in urban and suburban areas. Real-time optimization of delivery routes is also helped by mobile apps based on global positioning systems, which provide up-to-date information on road conditions. However, these have been widely implemented in recent years and the remaining savings are unlikely to be large.

4.3. Encouraging Improvements in Vehicles, Facilities, and Operations

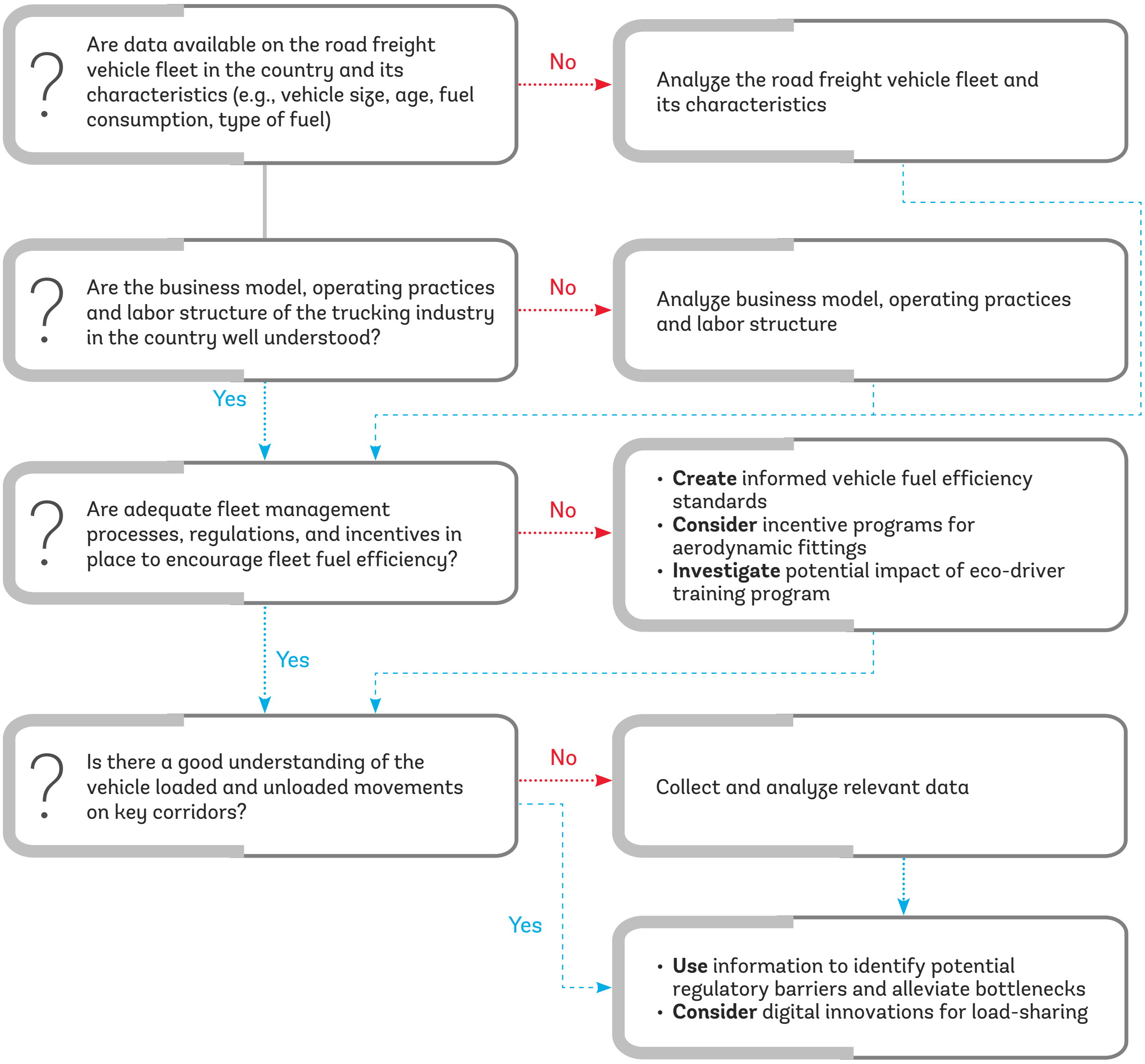
Most improvements in energy efficiency are made by manufacturers when designing new vehicles or by individual companies when selecting from them. However, governments can influence those choices in a green direction.

The trucking sector generates over half of logistics' GHG emissions, so measures to increase truck efficiency, while incremental, can have a positive impact on GHG emissions. Many HICs already set standards for new truck fuel efficiency. Larger LMICs are following suit. China, for example, has set national standards limiting fuel consumption of new, heavy-duty vehicles with diesel and gasoline engines, including heavy commercial trucks, tractors, and dump trucks (Delgado 2016). India has also established fuel standards for new trucks (Goswami 2022). Similar standards could be set by LMICs, even those that rely on used vehicles, either by imposing standards at import or when licensing or registering a truck purchase. Higher fuel efficiency standards are sometimes coupled with a voluntary scrapping and replacement program for the oldest and least efficient vehicles. These scrappage programs often involve the participation of commercial or development banks and other financial intermediaries.

Better standards for truck fuel efficiency help mitigate GHG emissions from diesel-powered vehicles in the near term and the fleet records and management systems accompanying those standards can also support longer-term switch to alternative fuel vehicles for medium and heavy trucks. Crafting such regulations is likely to require a deeper understanding of the freight vehicle fleet as well as the trucking industry's business model, operating practice, and labor structure (figure 4.3).

[18] For example, in the UK, 40 percent of vehicle-km and 14 percent of GHG emissions are from LCVs with a gross weight of 3.5 tons or less. Nearly 40 percent of these vehicles made multiple deliveries during the day. (UK Department for Transport, 2021).

Figure 4.3. Key Questions and Policies for Improving Technical and Operational Efficiency of Trucks[19]



Source: Original figure produced for this publication.

[19] A similar process of inquiry could be followed for logistics facilities and other transport modes such as rail and waterway.

Governments can also increase the efficiency of road transport by reducing regulatory barriers limiting truck operations and by supporting digital innovations in the private sector, such as load finding apps. Geographic limits on where trucks can operate, such as provincial, state, or national borders, make freight transport significantly less efficient, requiring re-handling of goods. Removing these limits can improve trade facilitation, boost economic growth, and reduce GHG emissions (image 4.3). Similarly, removing undue restrictions on firm size or industry consolidation to encourage the growth of logistics centers can unlock economies of scale in the handling of goods while mitigating climate change.

Image 4.2. Border Information Center in West Africa Established to Facilitate Inter-regional Trade

Source: USAID West Africa Trade Hub.

Energy efficiency regulation can also be applied to increase the energy efficiency of vessels and cargo aircraft. At the international level, the IMO has already adopted certain energy efficiency policies such as the Energy Efficiency Design Index, the Ship Energy Efficiency Management Plan, the Energy Efficiency Design Index for existing ships, and the Carbon Intensity Indicator. There is also significant scope to replace older aircraft with more efficient models for dedicated cargo operations, which typically employ older, and hence, more polluting planes.

Further, governments can promote awareness campaigns. These can be both economy-wide and aimed at individual transport market segments, with the objectives of raising awareness of energy efficiency and the scope for improvement (box 4.4).

Box 4.4. Promoting Knowledge in the Logistic Sector: The Brazilian Green Logistics Program

The Brazilian Green Logistics Program (*Programa de Logística Verde Brasil,* [PLVB]) is an initiative of freight and logistics companies aimed at promoting sustainable practices in logistics and transportation throughout Brazil. The program seeks to generate, consolidate, dispense, and apply knowledge with the goal of reducing GHG emissions, while also improving the efficiency of the freight and logistics network in the country.

PLVB promotes the adoption of best practices in logistics and transportation, including the utilization of cleaner fuels, the deployment of intelligent transportation systems, and the establishment of sustainable infrastructure. This is accomplished by drawing on existing programs within member companies as examples of such best practices, as well as incorporating relevant national and international experience.

The program envisioned the introduction of a freight transport Green Label Recognition System, which defines a benchmark for measuring, reporting, and verifying vehicle emission data. This recognition system will enable participating companies to compare their sustainability efforts and track progress toward reducing GHG emissions in their daily freight and logistics operations.

Sources: PLVB 2023; Freitas, D'Agosto and Marujo 2021.

5 Adopting Alternative Fuels

Key Messages

- **If logistics is to even approach the 2050 target of net-zero emissions, widespread substitution of carbon-based fuels by low- or zero-carbon alternatives is necessary.**
- **Potentially, green fuels include electricity (delivered by batteries or fixed infrastructure), biofuels, hydrogen, and ammonia (burned directly or in fuel cells), or synthetic carbon-based fuels.**
- **To minimize GHG emissions, the electricity used directly or in producing hydrogen or hydrogen-derived fuels must be green. This means a huge expansion of green power production.**
- **Different fuel technologies are more suited to different applications and are at different stages of development. Road freight is most likely to use biofuels or electricity (either directly, from batteries or from hydrogen-powered fuel cells). Rail freight is expected to be mostly electrified with a future role for hydrogen fuel cells. Maritime shipping will probably use ammonia, hydrogen, or e-methanol as zero-carbon bunker fuels to decarbonize at large scale, while IWT appears more amenable to electrification or pure hydrogen. Aviation is expected to use a mix of biofuels and e-kerosene.**
- **The relative costs and availability of the fuel options in the future are unknown.**
- **Governments can encourage adoption of lower GHG emitting fuels through taxation/pricing mechanisms that discourage the use of fossil fuels and support the development of charging infrastructure for battery-powered trucks.**

Eliminating GHG emissions from logistics will require large-scale conversion of vehicle fleets to greener fuels. While spatial planning and transportation demand management, mode shift, and vehicle and operational improvement measures discussed in Chapters 2-4 are beneficial and can deliver immediate benefits, in aggregate they probably represent a 25–30 percent reduction at most in logistics emissions. The hard to abate areas—long haul trucking, maritime and air—represent the majority of logistics emissions and these emissions can only be eliminated through widespread adoption of green alternatives to fossil fuels.

5.1. Fuel Quality

In the near-term, there is significant scope for LMICs to improve the quality and type of the fossil fuels already consumed by their truck, vessel, and airplane fleets. Currently, most of the vehicles and vessels used in logistics have internal combustion engines (ICEs), which overwhelmingly burn fossil fuel for power. While the combustion of all fossil fuels emits GHG emissions, the type and quality of fossil fuel can have a significant impact on the total emissions generated.

While fuel quality standards are most often adopted to control emissions of local air pollutants and improve air quality, they can also help reduce GHG emissions. For example, the Intergovernmental Panel on Climate Change (IPCC)'s Emissions Factor Database demonstrates how much the GHG emissions per unit of energy from fossil fuels can vary based on how that fuel is produced/refined and distributed. Diesel fuel used in trucks, for example, varies from around 72,600 kg CO_2 per TJ of fuel consumed to 74,800 kg CO_2 per TJ of fuel consumed. Given that the average truck operating in the US in 2020 consumed nearly 9,540 gallons of diesel fuel, this difference in fuel quality could amount to a difference in annual GHG emissions of nearly 3.1 tCO_2 for a single truck.

For logistics vehicles that already have electric motors, greening the electricity grid can help eliminate GHG emissions. Green electricity is already used in some places to power electrification networks for rail and charge batteries for shunting locomotives, delivery trucks, and local IWT vessels.

5.2. Alternative Fuel Options

There are a range of alternative energy and fuel sources being developed with potential application for logistics. Electric power may be supplied by battery, fuel cell, or fixed infrastructure, and alternative fuels include natural gas (for example, compressed natural gas [CNG], liquefied natural gas [LNG]), biofuels, methane, ammonia, hydrogen, and synthetic carbon-based fuels (for example, e-methanol or e-kerosene) (see Annex A). Some of these alternative fuels are already commercially produced and can 'drop-in' to existing engines. Other options are still in the demonstration stage and would require overhauling energy/fuel distribution systems as well as vehicle engines to serve transport end-use at scale. Therefore, the choice of fuel involves critical tradeoffs in terms of scalability, cost, and potential GHG emissions reductions. When comparing across options, it is critical to consider GHG emissions not just from a TTW basis, but from a WTW basis covering the production, distribution, and end use of the fuel or energy.

Electricity

Electricity is typically the most familiar alternative energy source for transportation. Its "greenness" as a transport fuel depends on how the electricity is produced. The electricity can be delivered to freight vehicles through fixed infrastructure (such as overhead catenary, third rail) or through charging energy storage devices such as batteries. Batteries are starting to be used in freight vehicles that travel short distances and can tolerate relatively long (for example, overnight) recharging time. Battery technology is improving rapidly, with reductions in the size, weight, and recharging time required, while extending the power stored (thereby extending the range of the vehicle powered).

Methane

Methane can, at best, be regarded as a transition fuel (Englert and Losos 2021). An ICE can be designed to run on methane, although with lower performance than with diesel fuel. The methane is normally provided as CNG or LNG and, increasingly, as biomethane. CNG and LNG must be stored in cylinders (cryogenic cylinders for LNG). Due to their lower energy density, a vehicle operating with CNG/LNG needs up to six times (for CNG) or twice (for LNG) the fuel storage space that an equivalent diesel engine would need.

Although CNG and LNG generate less CO_2 per unit of energy burned than diesel, they both suffer from "methane slip" or "methane leakage." This refers to the incomplete combustion of the fuel or the escape of methane during production and distribution. Methane has a high global warming potential—one gram of methane released into the atmosphere has the global warming potential of at least 25 grams of CO_2 over a 100-year period. Therefore, methane slip can limit or even eliminate the overall

CO_2e benefits of using methane. Estimates of the GHG benefits of natural gas relative to diesel range from 20 percent (based purely on the fuel properties) to no-net GHG benefits or even GHG disbenefits when engine performance and methane slip/leakage are considered. A big advantage of natural gas over diesel is that it significantly reduces the emissions of hydrocarbons and local air pollutants such as carbon monoxide (CO), nitrogen oxides, and particulate matter. However, it is not likely to help decarbonize logistics in a meaningful way.

Biofuels

Biofuels are derived from material that would otherwise naturally decay and emit GHGs. The "greenness" or reduction in GHG emissions comes from the difference between the GHG that is absorbed and emitted when it is used as an energy source compared to the GHG emissions that would occur if the material were left to decay naturally (discussed briefly in Annex A). There are many varieties of potential biofuels that can be used as bio-diesel or bio-kerosene. Some have been used for decades and are drop-in fuels, but others are still barely at the demonstration stage. Once produced, a major advantage of biofuels is that they can be distributed in exactly the same way as fossil fuels, making use of the existing transport refueling infrastructure. Their major challenge though is that the amount of sustainably sourced biomass, which can be used for biofuel production without entering into conflicts with food security or direct and indirect land-use change, is limited.

The low availability of sustainable biomass may limit the use of biofuels. Two main factors which govern the availability of biofuels are:

- *Quantity that can be produced sustainably.* The total future global bioenergy production is uncertain. Many experts agree that approximately 70 to 160 exajoules (EJ) of energy can be produced from sustainable biomass by 2050 (UK Committee on Climate Change 2018; Smith et al. 2014) with the IEA citing 100 EJ of bioenergy by 2050 in their Net Zero Emissions scenario (Gül, Cozzi, and Havlik 2021). However, the full range in the literature is much broader, with estimates ranging from 30 to 500 EJ (Fuss et al. 2018;Pye et al. 2019).

- *Cross-sector competition*. Biofuels can be used to decarbonize many sectors. The International Council on Clean Transportation considered that the supply of the most-used feedstock for liquefied bio-methane (livestock manure, food-processing waste, and sewage sludge) could be most efficiently used for onsite power generation (Pavlenko and Araujo 2019). The UK Committee on Climate Change (2018) concluded that the priority uses of biomass should be in the construction and in the energy sectors to produce aviation fuel, hydrogen, and electricity, if carbon capture and storage (CCS) technologies become available.

Within the transport sector, biodiesel can be used in any diesel engine. If supply is limited, it should be prioritized for subsectors, such as aviation, that are most in need of high-energy-density fuels and suffer from a lack of other alternatives.

Hydrogen

The emission benefits of hydrogen fuel depend entirely on how it is produced. Although hydrogen is an abundant gas, it is difficult to extract directly and must be manufactured. Once produced and distributed, it can be burned directly in a combustion engine or used in a fuel cell to power an electric engine.

Currently, most hydrogen is produced by large-scale steam methane reforming, which produces CO_2 as a byproduct. This multi-step process reacts methane (CH_4) from natural gas with steam (gaseous H_2O) to produce hydrogen (H_2), carbon monoxide (CO), and CO_2. The hydrogen produced this way has higher GHG emissions per unit of energy than petroleum-based fuels (1.3-1.8 or greater depending on how the hydrogen is distributed). In such cases, CCS of the CO_2 would be necessary to achieve lower GHG emissions than with current transport fuels, but CCS technology is still in the development stage.

Alternatively, hydrogen can be produced by electrolysis. This process uses electricity to split water (H_2O) molecules into H2 and oxygen (O2). When the electricity for the electrolysis is green, the hydrogen produced by it will also be green. However, the energy losses in production and subsequent use as a fuel are high. If electricity emissions are greater than about 300 gCO_2e/kWh, using hydrogen as a transport fuel rather than diesel will result in more emissions. Many LMICs are above 300 gCO_2e/kWh. For example, in 2019, China's grid was at 610 gCO_2e/kWh and India's was at 735 gCO_2e/kWh.

Other hydrogen production pathways include methane pyrolysis or microbial conversion of biomass. The decomposition of methane from natural gas could require half the energy required by steam methane reformation to produce the same amount of hydrogen and it produces a solid rather than gaseous carbon by-product, limiting GHG release into the atmosphere and the need for CCS. In the longer-term, there is the possibility of using a biological process whereby microbes convert biomass to hydrogen instead of methane. These processes are being developed at both laboratory scale and at a demonstration level.

To distribute hydrogen, producers need to cool it to -253 degrees Celsius to liquefy it, pressurize it (typically 35-70 megapascals or Mpa) to reduce its volume, or convert it in a chemical process to an alternative carrier; all these options are likely to require a dedicated distribution network. When used, it requires heavy-duty fuel tanks on vehicles (the hydrogen itself only represents about 6 percent of the total weight of itself and its tanks). Hydrogen is not toxic, nor does it produce toxic products when burnt. Therefore, while it has a global warming potential of around 11, hydrogen leaks or spills will disperse rapidly and not contaminate the local environment like a spill of petroleum fuel. It also needs more oxygen than petroleum fuels, despite its high flammability and low ignition energy. Hydrogen has been in general industrial use for many decades and relevant standards have been developed for its handling and storage. These would need substantial development for application to transport.

Ammonia

Thanks to its higher energy density and less demanding cooling requirements, ammonia (NH^3) is easier to transport than hydrogen. Yet, it is more toxic than hydrogen and requires strict controls on how it is handled and transported. Today, ammonia is manufactured in large quantities using a well-established process (the Haber-Bosch process), which combines nitrogen from the atmosphere with hydrogen (currently largely derived from natural gas) to form ammonia. This process requires substantial quantities of electricity. Both the electricity and the hydrogen need to be produced in a green way for ammonia to become a green source of energy.

Synthetic (Carbon-Based) Fuels

Synthetic (carbon-based) fuels are gaseous and liquid fuels produced from hydrogen and captured/recycled biogenic CO_2 using green electricity as the principal power source. They are also known as power-to-gas/liquid (PtX) fuels or e-fuels. Their main advantages are that, like the biofuels, they have a relatively high energy density, can use the existing energy infrastructure, and are compatible with existing ICEs, with slight modifications.

Green electricity or a green way of generating heat is a critical requirement for almost all alternative fuel options. While LMICs are rapidly expanding access to electricity and grids are becoming greener, the availability and carbon intensity of electricity is an important consideration in the production of hydrogen, ammonia, and synthetic carbon-based fuels. When powering vehicles directly with green hydrogen, the distribution and storage of green electrons is a critical concern. However, the use of green electricity to produce other liquid fuels, such as hydrogen, can be an alternative method of storing and transporting clean energy.

5.3. Viability of Alternative Fuel Options

The use of these fuels for different applications depends on four main characteristics:

- *Technical readiness:* the technical characteristics such as power density and energy density,[20] durability, overall energy efficiency, storage options, and maintainability, as well as fuel availability
- *Infrastructure readiness:* the availability of storage, distribution, and fueling infrastructure
- *Economic viability:* delivered fuel cost, capital cost of introducing fuel and its supporting infrastructure
- *Environmental impacts*: lifecycle resource and energy impacts

The transport sector typically needs energy sources, which are portable and can be readily resupplied. A particular strength of petroleum products is their high energy density (high amount of energy stored for the volume and weight of the fuel). This means that petroleum fueled vehicles can carry their own supply of fuel with less loss of carrying capacity compared to low-density energy sources such as lithium batteries, hydrogen (even when liquefied), or ammonia (figure A.2).[21] Biofuels and most synthetic carbon-based fuels have similar energy density to petroleum fuels. The direct supply of electricity through overhead or underground wires also has high energy density.

The impact of fuel density depends on how much fuel is required between replenishments. An electric vehicle (EV) used for local delivery, traveling 100 km per day with 500 kg of freight would need only about 400 kg of batteries (and maybe half of that in the future as battery technology develops). A long-distance truck carrying a 20 tons payload for 500 km could need 8-10 tons of batteries,

[20] Energy density by volume measures the amount of energy in a given volume (MJ/litre). As gases such as hydrogen are compressible, this value will depend on the pressure at which it is stored. Energy density by mass measures the amount of energy in a given mass (MJ/kg); this is independent of pressure. Power density measures the power (energy per unit of time) that a system can supply by a combination of a fuel and a delivery system. The overall energy efficiency includes the energy used to create the fuel.

[21] Figure a.2 includes the weight of the fuel containers as well as the fuel/energy itself. As an example of the importance of the containers, hydrogen itself, even at 700 bar, only represents about 6 percent of the total weight of itself and the vessels in which it is stored. Diesel, in contrast, is over 95 percent of the combined weight of itself and the typical heavy-duty truck fuel tank (based on an empty 150-gallon tank weight of 45 lbs and a weight of diesel fuel of 7 lbs per gallon).

severely affecting its potential payload.[22] Fuel cells are much more economical in terms of both mass and volume, with the combined mass of the hydrogen tanks and fuel cells being about 10-15 percent of the mass (and 40 percent of the volume) of the batteries needed for an equivalent amount of power. However, the energy efficiency of fuel cells is less than half of that of batteries, which is an important consideration when the production of green electricity (and hence, green hydrogen) is limited. Biofuels, however, would only generate small fuel density penalties compared to petroleum-based fuels.

Fuel supply is also an important consideration. Biofuels and most synthetic carbon-based fuels could use the existing petroleum fuel storage and distribution networks. Hydrogen, ammonia, and batteries would all need specific supply arrangements. Hydrogen can be liquefied, but this requires it to be transported at very low temperatures, an impractical requirement for general users. Today, it is often transported after being heavily compressed (to either 350 or 700 atmospheres), which requires strong containers. Ammonia, by contrast, can be transported as a liquid at around 10 atmospheres. Batteries will need periodic recharging, ideally at facilities, which can provide fast charging. In many countries, this would require the electric grid to be strengthened to provide the requisite volume of electricity.

The cost of most alternative fuels depends substantially on the cost of green electricity. While the cost of electricity varies substantially, a recent report found the average cost of electricity from newly commissioned renewable sources in 2021 ranged from US 3.3 c/kWh for onshore wind to US 11.4 c/kWh for concentrated solar power (IRENA 2022).[23] It seems clear that green electricity is already cost competitive against fossil fuels.

The cost of adopting an alternative fuel includes the cost of the fuel and the cost of the associated processes, vehicles, and distribution infrastructure. For freight transport operators, a key consideration will be the at-pump cost to dispense the fuel or to charge. Usually, this cost will reflect the cost of fuel production and distribution (typically covering some portion of this infrastructure). The decisions governing these costs are often made outside of the transport sector but have significant impact on the end use of the fuel for freight transport. For example, the delivery of electricity through overhead or underground wires involves substantial investment in electric power supply infrastructure, making the approach economically viable only on the more intensively used parts of the highway and railway networks. For other technologies, the costs are subject to a wide range of uncertainty as the technologies are developed and moved to industrial production at scale. Even for technologies already being commercially trialed, such as battery and fuel cell electric heavy trucks, studies show that forecasted costs had uncertainties greater than the estimated value by 2050 (Craglia 2022). Many of the other proposed fuels are still at the research stage and the costs for their implementation at scale are far less certain.

Many of the alternative fuels could have close to zero life-cycle emissions. These include electricity, hydrogen and ammonia, if manufactured using green electricity, synthetic carbon-based fuels (e-methanol or e-kerosene), if their source of CO_2 is of biogenic origin), and some biofuels. On a life-cycle basis, none of the alternatives have exactly zero emissions, as their manufacturing processes have varying amounts of embedded emissions (such as the towers and blades of wind turbines, together with the maintenance effort). However, these are mostly small (10-50 gCO_2e) (for example, Gibon, Menacho, and Guiton 2021) compared to the emissions of conventional power plants.

[22] Although a large electric truck would save two to three tons by not needing a diesel engine and associated equipment.

[23] A system that uses mirrors or similar devices to concentrate the sun's rays on a specific point, creating solar thermal energy.

Table 5.1 summarizes the key characteristics of each fuel/technology combination. The table includes fossil fuels currently in common use in the freight transport sector as well as possible alternatives. Each fuel is rated in terms of its technical readiness, storage distribution and fueling, energy efficiency, economic viability, and life-cycle GHG emissions. Technical readiness and storage, distribution, and fueling are rated based on the commercial availability of the technology: "Absent", "Research", "Trial", "Limited", "Advanced," or fully "Commercialized." Energy efficiency, economic viability, and life-cycle emissions are rated qualitatively as "Poor", "Average", "Good", or "Excellent." As the processes and infrastructure needed to produce and distribute many of these alternative fuels at-scale are still under development, and as they often involve important tradeoffs among technical readiness, infrastructure readiness, economic viability, and environmental impact, no one fuel can be identified as the dominant technology/fuel of the future in freight transport.

Table 5.1. Characteristics of Alternative Energy Sources

Technology/fuel	Technical readiness	Storage, distribution and fueling	Energy efficiency (%)	Economic viability	Life-cycle emissions
ICE					
Petroleum-based fuels	Commercial	Commercial	Excellent	Excellent	Poor
Natural gas (CNG, LNG)	Commercial	Advanced	Good	Excellent	Poor
Green hydrogen	Trial	Absent	Average	Average	Excellent
Green ammonia	Trial	Trial	Average	Average	Excellent
Synthetic carbon-based fuels	Research	Commercial	Average	Poor	Excellent
Biofuels	Commercial	Commercial	Excellent	Average-Good	Poor-Excellent
Electricity (direct)					
Battery electricity	Commercial	Limited	Good	Average	Excellent
External electricity	Commercial	Trial	Excellent	Good	Excellent
Fuel cell					
Hydrogen	Trial	Absent	Good	Average	Excellent
Ammonia	Trial	Limited	Good	Average	Excellent

Source: Original table produced for this publication.

5.4. Modal Options

The different characteristics of these fuels align differently with the requirements of the different modes of transport. Shipping, for example, has more concentrated fueling points at ports, making it more suited to using hydrogen or ammonia than trucking, which requires a more dispersed network for refueling. Even within modes, one segment may be more suited to a particular fuel option. Electric batteries, for example, are already being used in LCVs, but not yet in commercial use for heavy, long-haul vehicles.

Road Freight

The main long-term options for road freight are electricity (either battery or by direct connection), biofuels, and hydrogen (or ammonia), either by direct combustion or with a fuel cell. All can theoretically be used to power road vehicles[24] and hydrogen is already undergoing a major field trial. A problem in past years has been the difficulty of finding a robust fuel cell for ammonia but the development of the solid oxide fuel cell should provide it with wider opportunities.

Electricity can be supplied in two ways, either by direct supply or by storage in batteries. Direct supply has potential where large volumes of trucks move between major nodes. The direct supply would power the linehaul component of the trip and battery-supplied electricity would fuel the access and egress legs of the trip. Two types of direct supply have been proposed. One is overhead catenary lines, combined with retractable pantographs on trucks. The other is the inductive transfer of power from coils embedded in the roadway. Both technologies are being trialed in countries in Europe, including Germany, Sweden, and the UK (Volkswagen Group News 2020; Jolly 2021; Edelstein 2020).

The use of batteries in trucks is currently limited by the size and weight of the batteries required as well as the charging times needed to replenish these large batteries. Battery size and weight is driven by the amount of power that needs to be stored between charging. Battery technology has made rapid advances in the last decade, both in terms of energy density (kWh/kg) and in terms of cost.

Today, commercial vehicles with lower gross vehicle weight and mileage, such as urban delivery vehicles and cargo vans, are already well-suited to battery operation. This is particularly true when these vehicles are parked overnight in dedicated depots where they can recharge their batteries. There are an increasing number of battery-electric medium-duty trucks and vans in markets such as the U.S., where they accounted for 75 percent of all zero-emission truck deployments in 2021 (Al-Alawi et al. 2022).

However, using batteries in heavy-duty vehicles and for long-haul operations is still at the developmental stage with only a few ongoing commercial trials. A long-distance truck carrying 20 tons of freight would currently need a battery pack weighing eight tons to travel 500 km, at which point the batteries would need to be recharged. Longer trips without recharging would need a correspondingly greater weight of batteries, which would drastically cut into the available payload of trucks that already operate on very slim profit margins. While heavy-duty trucks accounted for only 4 percent of zero-emission truck deployments in 2021 in the U.S., the numbers are expected to grow (Al-Alawi et al., 2022). Technology is rapidly evolving, heavy-duty vehicle manufacturers are announcing ambitious goals for truck electrification, and commercial trials are ongoing around the world. For example, Scania has committing to being fully electric by 2040 and Volvo Trucks aim for 50 percent of its vehicle deliveries to be electric by 2030.

[24] Although both fuels have been used intermittently for many decades on a smaller scale.

Green fuels for use with ICE include hydrogen, ammonia, and biofuels. Biofuels can already be blended with ordinary diesel fuel and distributed through the same fueling network. Hydrogen and ammonia both require much larger and more elaborate storage space on the vehicle, specialized distribution systems, and special fueling points. Thus, they would be best suited to operations between a limited number of locations with refueling points, such as ports, major distribution or consolidation centers, and multimodal transfer facilities.

Trucks using hydrogen fuel cells are essentially EVs using hydrogen stored in a cryogenic or pressurized tank and equipped with a fuel cell for on-board power generation. Hydrogen storage requires approximately four times more space to achieve the same range as conventional diesel technology. Many trials have already been made in different countries. Although costs are currently high, the unit costs of fuel cells and on-board storage tanks are expected to reduce markedly over the next decades.

An alternative use of hydrogen is its direct combustion as a 'drop in' fuel in ICE vehicles. This option has many practical advantages, particularly in the context of LMICs. First, existing vehicles can be retrofit at a much lower cost than the purchase cost of a new, hydrogen fuel cell vehicle. In LMICs where truck operations are fragmented and single owner-operator businesses lack access to financing for fleet renewal, reducing the upfront capital cost barrier to using alternative fuels will be critical to encouraging adoption. Second, fuel cell performance is extremely sensitive to the purity of hydrogen introduced whereas the direct combustion of hydrogen does not have such strict requirements for fuel quality (Jones 2022). In LMICs where regulation and enforcement of quality for existing diesel and petrol fuels is still limited, adopting the more robust engines may be a lower risk investment for truck owners.

Several studies compare the operating cost and the cost of new infrastructure, where needed, of the various fuel options. The results show the costs of the environmentally acceptable fuels in 2050 are roughly equivalent (Teter, Cazzola and Gül 2017; Jones 2022). Thus, forecasting which technology will prevail is not possible. Different subsectors of road freight are likely to be served by different solutions. Most urban and suburban delivery vehicles, which typically have lighter loads and travel less than 80 km from their base, seem promising candidates for battery power. Trucks traveling farther with heavier loads are likely to consider the other fuel options too.

Rail Freight

Currently, two broad groups of locomotives are employed in transporting freight by rail. Diesel-electric locomotives burn diesel fuel in an ICE to generate electricity to power the locomotive. Electric locomotives draw energy from an external source, usually an overhead power line. Apart from the diesel engine and generator in the diesel-electric locomotive, and the current collection equipment and transformer in the electric locomotive, the other components of the locomotives are similar (Lawrence and Bullock 2022).

Just over half the rail freight in the world is already transported on electrified railways. Since overhead electric power supply systems are costly, they are economically viable for lines that carry large volumes of freight. Batteries are being trialed for lower-powered locomotives used for shunting and running short distances to collect or deliver freight to local sidings.[25] Pure battery operation of mainline freight trains will require both robust high-capacity batteries and recharging facilities that can handle heavy loads without disrupting the main electric distribution network.

[25] Mainline services are already operating in which one of a group of four locomotives is battery powered. Its batteries are recharged through regeneration on downhill stretches, which enable it to provide additional power on uphill sections.

Manufacturers are developing locomotives with hydrogen fuel cells or that can directly burn hydrogen instead of diesel fuel. Many operational challenges have been identified with the use of hydrogen fuel cells for locomotives and need to be addressed before they are used for mainline operations (Fullerton and Dick 2015). However, others are considering the use of hydrogen as a drop-in fuel for combustion locomotives, which can be converted from diesel to hydrogen relatively quickly and affordably compared to a full replacement with a fuel cell.

Maritime Shipping

Shipping is currently fueled almost exclusively by heavy fuel oil (HFO), which emits CO_2 and significant quantities of air pollutants. For many years, LNG was proposed as a cleaner alternative. While it offers undoubtedly significant air quality benefits, its inherent risk of methane slip/leakage along the entire supply chain—from production to distribution and combustion—makes its GHG advantage over HFO uncertain. Depending on the assumptions, which range from very optimistic to very pessimistic, LNG as a bunker fuel may lead to anything from 8 percent GHG benefits to 9 percent GHG disbenefits (Englert et al. 2021). A consensus exists that a truly green fuel—green hydrogen, green ammonia, or green e-methanol—will be required, together with modified ICEs or fuel cells, to decarbonize shipping. Due to the limited supply of sustainable biomass and cross-sectoral competition (among others, from aviation), biofuels are expected to make only a minor contribution to shipping's decarbonization.[26]

Hydrogen, ammonia, and methanol would all be technically possible, but ammonia has some significant advantages (Hansson et al. 2020). For long voyages, while ammonia, hydrogen, and methanol all need more storage space than HFO, resulting in a loss of cargo space, ammonia and methanol allow more storage space than hydrogen. Hydrogen would require about one-third more storage space than ammonia. A study by Lloyd's Register and UMAS (2020) calculated this trade-off for specific ship types and sizes and concluded that green ammonia was consistently the most cost-effective alternative fuel in the long run, with blue ammonia being the least costly in the medium term. While even more space-efficient than ammonia, methanol requires a biogenic source of CO_2 for production, making it potentially more costly than ammonia.[27] The only vessels currently operating with hydrogen are all deployed on short-distance routes (for example, ferries).

Inland Waterways

IWT has similar options to road for replacing diesel with biofuels in the existing ICE fleet and for replacing diesel motors with electric ones, powered by either batteries or hydrogen fuel cells. IWT fleets typically have long lives, so the process of conversion through natural attrition may be too slow.

The benefits and challenges of the alternatives include (Dundon et al. 2021; BMVI 2019):

- Biofuels have an energy density similar to diesel's and require minimal vessel modification. Existing storage and fueling facilities could handle biofuels.

[26] Without a breakthrough in aquatic biomass production, biofuels will probably play only a minor role in shipping's future energy mix as they are unlikely to be available at scale nor be sufficiently cost-competitive (UK Committee on Climate Change 2018).

[27] In many cases, this biogenic CO_2 can only come from direct air capture whose cost effectiveness and scalability is yet to be proven.

- Battery electricity has become increasingly competitive in recent years. Previous constraints of lack of power and range are being addressed, at least for the smaller vessels. Since 2017, two battery electric-driven vessels have operated in the ports of Rotterdam and Antwerp.
- Hydrogen is likely to be combined with fuel cells. Vessel engine modifications would be substantial, and vessels would require cryogenic or pressurized fuel tanks. New distribution and fueling facilities would be required.

In summary, alternative drop-in biofuels could play a major role in reducing the carbon footprint of IWT. However, their availability and the related bunkering costs are hard to predict and will depend on the priority given to other transport modes, particularly aviation. Considering the much shorter distances traveled and lighter loads carried, IWT can be electrified much more easily than maritime shipping using battery electricity. At the same time, IWT is also more amenable to the use of hydrogen over ammonia—despite hydrogen's lower energy density—as refueling can happen more frequently and easily along the journeys.

Aviation

A recent report identified several technical issues that needed to be overcome before hydrogen could play a significant role as an aviation fuel (McKinsey & Company 2020):

- need for lighter fuel tanks and fuel cell systems
- distribution of liquid hydrogen within the aircraft
- need for turbines capable of burning hydrogen with low-NOx emissions
- development of efficient refueling technologies

Electric propulsion is also possible in the longer term but again, probably only for short-distance flights, such as commuter and regional services.

Image 5.1. Cargo Plane

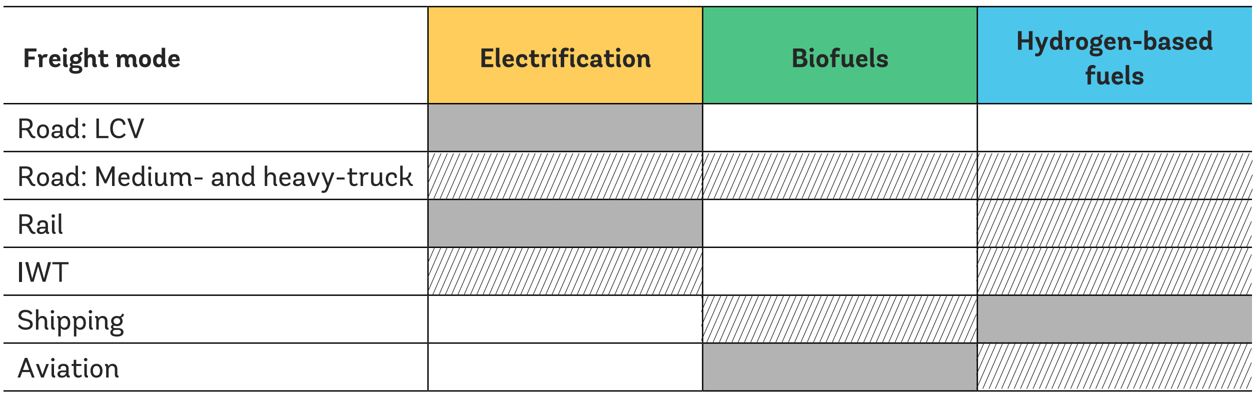
Source: Adobe Stock.

The main alternative fuels for aviation are what is known as sustainable aviation fuel (SAF). These are a set of fuels that can be sustainably produced and generate lower CO_2 emissions than conventional kerosene on a life-cycle basis. Their feedstocks include several biomass crops and residues, which can be converted into jet fuel through a range of technologies. Another approach is through a synthetic carbon-based fuel such as e-kerosene. Such SAF can be blended with conventional jet fuel (today already permissible up to 50 percent) and used with the existing aircraft engine and fuel system. Tests are ongoing to assess if higher blending percentages up to pure SAF usage are compatible with aircraft engine and fuel systems.

Detailed scenario analysis suggests SAF production could cover between 30–60 percent of global demand by 2050. This would still be only a small share of the total potential bioenergy by 2050. Currently, SAF accounts only for 0.1 percent of global fuel demand and it costs up to three to five times more than Jet-A. Its availability is also limited to select airports in OECD countries where there are several SAF uptake mandates and production incentives.

Figure 5.1 summarizes the discussion in this chapter and ranks each of the potential alternative fuels in terms of their technical suitability for each mode.

Figure 5.1. Most Promising Application of Alternative Fuels by Mode



Source: Original figure produced for this publication.

Note: = moderate potential; = strong potential. Hydrogen based fuels include ammonia.

5.5. Options for Logistics Facilities

Warehousing and other logistics facilities generate 9 percent of total logistics GHG emissions, making it the third highest generator of logistics emissions after trucking and shipping. The emissions stem primarily from the energy used to heat, cool, and light warehouse buildings. Simple solutions for reducing emissions include installation of LED lights, insulation, and rooftop solar, which save energy costs over time. “The large, flat roofs of most warehouses provide an ideal surface for installing solar panels” (Moul 2022). Logistics facilities can convert their powered equipment from diesel to alternative fuels as soon as the life-cycle emissions of these vehicles are competitive with diesel. Electrification of warehousing equipment could be coupled with the fitting of solar panels on the large roof areas prevalent in warehouses and many terminals.

5.6. Encouraging Alternative Fuel Adoption

Governments have a range of tools to encourage the adoption of green fuels in logistics. Pricing/taxing mechanisms and regulation to discourage the use of fossil fuels can set the right framework conditions both domestically and internationally. Locally, governments can also ensure that the electric power supply network is robust enough to support the electrification of road and rail, and electricity production is green or greening. Where economically viable, governments can support developing the production and distribution of green fuels. International cooperation is needed to address international shipping and air freight.

Encouraging Alternative Fuels in Trucking

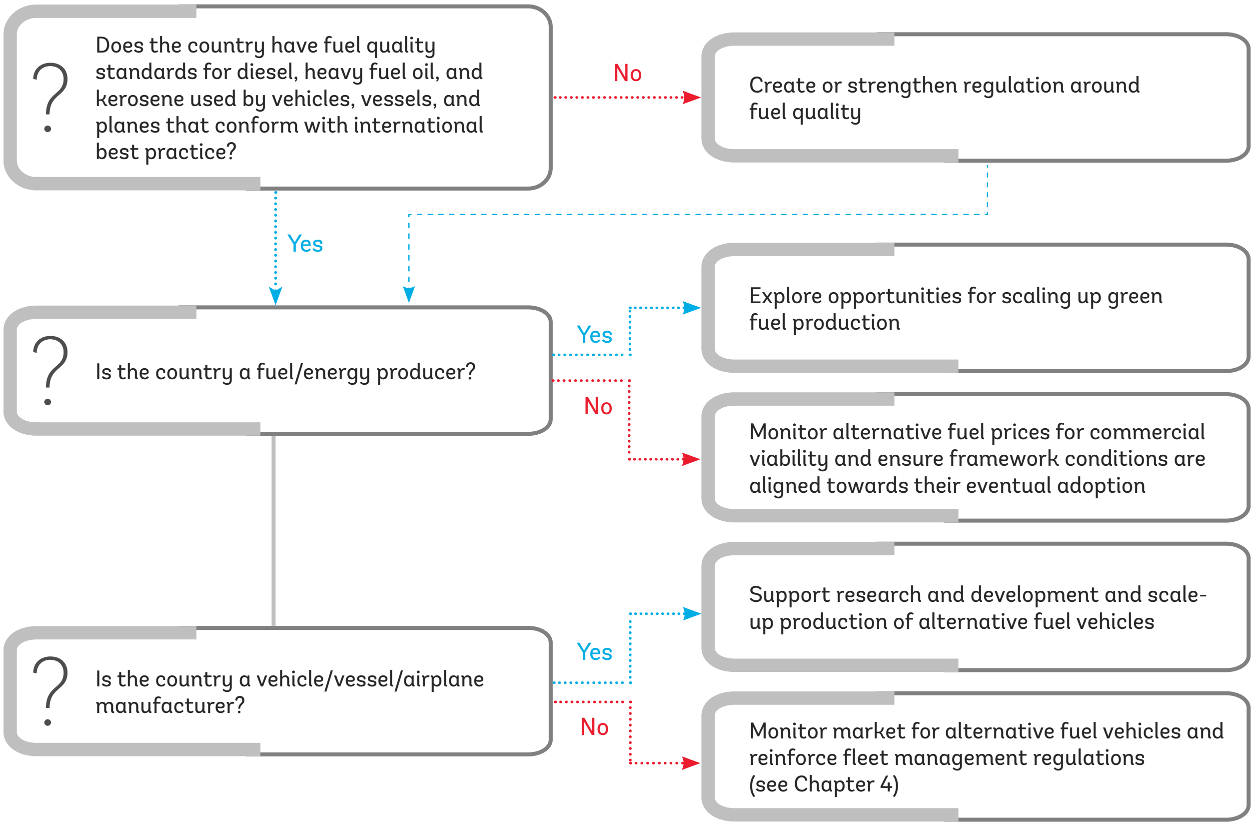
Fully addressing truck emissions will require powering trucks with green energy delivered in the form of batteries or fixed infrastructure electrification, hydrogen fuel cells, or other fuels and vehicle technologies. Battery EVs have made major technological advances over the past decade and are proving commercially viable for smaller vehicles. For freight transport, battery EV technology has already reached commercial viability for light duty vehicles used in last-mile deliveries, including the two- and three-wheelers often seen in cities in LMICs (Kok et al. 2023). Battery-powered LCVs are in commercial service in the urban areas in North America, Europe, and East Asia.[28] As the logical entry point for truck electrification, policymakers may wish to encourage the electrification of LCVs by:

- *ensuring power supply*. Examine the capacity of the electric power system to provide electricity for LCVs in urban areas, recognizing that the demand may create peak loading challenges at the end of the work day. Address the power supply issues before providing other incentives for electric LCVs.
- *supporting development of charging infrastructure.* Concerns about limited options to charge an EV is a barrier to its adoption. In many countries, governments provide financial support for the provision of public, on-street chargers. Governments can also make it easier for private firms offering charging by adapting land use rules or making land available for charge points.
- *subsidizing investment in electric LCVs.* Some countries provide subsidies or tax credits for investment in EVs. While effective, such programs can have significant fiscal implications.

Applications of battery electric power for heavy-duty freight transport segments, such as long-haul trucks, are still in the testing phase and issues such as the weight and size of batteries (reducing payload) and long recharging times remain a barrier to their widespread, commercial adoption. There may be opportunities for LMICs that are green energy producers or vehicle producers to scale-up research and development as well as investments in alternative fuels and vehicle technologies. However, for most LMICs, the best course of action may be to monitor the rapidly advancing developments in alternative fuel technology for medium and heavy trucks, with the intention of developing those segments when the technology is more mature (figure 5.2).

[28] Electrifying LCVs will not address other urban priorities such as reducing traffic congestion and traffic accidents.

Figure 5.2. Key Questions and Policies for Adopting Alternative Fuels for Heavy-Duty Trucks



Source: Original figure produced for this publication.

Encouraging Alternative Fuels in Rail

As an already energy-efficient mode of freight transport, rail's greatest role in reducing GHG emissions from freight logistics comes with its ability to attract traffic from trucking and other less energy-efficient modes—encouraging modal shift. For freight traffic already traveling by rail, the largest potential improvement in GHG emissions come from the electrification of diesel operations, if the electricity source is green. However, fixed electric power supply infrastructure needs a minimum traffic density (generally 5 to 10 million gross tons) for electrification to be commercially viable. The development of battery-electric and hydrogen traction, which are more suited to low-density operations, is occurring at a fast rate for local freight service and is likely to extend to mainline operations within a few years. Policies to encourage electrification of rail include:

- *Providing financial support for electrification technology.* While most railways will naturally favor GHG-reducing technology because of energy cost savings, they might not be able to make the required investment. Governments could accelerate these investments by funding them or supporting the railway to obtain low-cost financing. This would enable rail companies to invest in overhead electrification and electric locomotives where the technology is commercially viable.

- *Monitoring technical developments.* Railways and governments should follow the development of battery and hydrogen-powered traction and consider investing in them when the new technologies are suited to the railway's commercial requirements (Lawrence and Bullock 2022).

Encouraging Alternative Fuels in Facilities and Terminals

Policies to encourage logistics facilities to implement energy-saving technology and install solar often apply broadly to commercial buildings and should include warehouses. Such measures cover:

- *establishing a regulatory environment that enables distributed solar power.* This ensures that electric power utilities work with small solar operators in an equitable fashion.
- *providing financing for solar investment or creating vehicles to aggregate demand for multiple warehouses and companies.* Governments could provide direct financial support for companies to invest in rooftop solar at affordable rates (see box 5.1) or consider other innovative mechanisms for aggregating demand. This can help companies unlock economies of scale in procurement and reduce the risk of deploying a new technology. For example, this approach has seen recent success in bringing down the capital costs of electric bus procurement in India.
- *subsidizing investment in solar or other energy saving measures.* This may take a variety of forms including tax credits and direct subsidies. While effective, such programs can have significant fiscal implications.

Box 5.1. Rooftop Solar in India

In 2016, the World Bank launched a $625-million lending program with the State Bank of India (SBI) for rooftop solar units for the commercial, industrial, and institutional sectors. The loan enabled SBI to lend to private sector companies to develop India's commercial and industrial solar segment. To date, over 365 MW of capacity have been installed and commissioned under the program.

Source: Das (2016) and Shetty (2021).

Encouraging Alternative Fuels in Maritime Shipping and Aviation

To discourage the consumption of fossil fuels in maritime shipping, governments are strongly advised to eliminate existing subsidies and other support for fossil fuels and consider carbon pricing. To date, bunker fuels mostly benefit from significant or even full tax exemptions, which represent indirect fossil fuel subsidies. To address this issue, the European Commission, for instance, proposed in its revised Energy Taxation Directive a minimum taxation rate for intra-EU maritime (and air) transport (2021). Once governments eliminate such fiscal support for fossil fuels, rendering them more costly, they automatically discourage the consumption of these fuels. The same mechanism is used by putting a carbon price on bunker fuels, consequently discoursing their use (see Chapter 2).

Governments can support the shift to green fuels by fostering the demand for these fuels and/or incentivizing their supply, for instance either through a fuel mandate or a carbon price. Today, discussions at the IMO on how to facilitate the accelerated adoption of green fuels globally are considering both technical (for example, a mandate to use green fuels) and economic (for example, a carbon price on GHG emissions from fuels) measures. Governments have already tentatively agreed on a GHG fuel standard as the technical measure of choice to reduce the average carbon intensity of fuels over time. A complementary carbon price, in return, would help close the current cost competitiveness gap between relatively inexpensive fossil fuels and more expensive green fuels. Furthermore, revenues from such a carbon-pricing instrument could be used strategically to catalyze further climate and development action in developing countries (Dominioni et al. 2023). On top of this collective action, individual governments can also take national policy action to incentivize investments in zero-carbon bunker fuel production and supply through, for instance, feed-in tariffs for renewable power generation, direct subsidies, or fiscal incentives for pilot and demonstrator projects, or even own green procurement.

Aviation, accounting for 3 percent of global logistics GHG emissions, is a challenging sector to decarbonize. Like shipping, it will require shifting from traditional fuel (kerosene) to SAF. The ICAO defines SAF as renewable or waste-derived aviation fuel that meets the Carbon Offsetting and Reduction Scheme for International Aviation (ICAO 2022).

Measures to encourage the use of SAF are intended to create a market for it, encourage investment in production of SAF, and enhance its attractiveness relative to traditional aviation fuels. These measures include:

- *applying a carbon tax to traditional aviation fuel.* This is intended to make traditional aviation fuel more costly and relatively less attractive to airlines than SAF (see Chapter 2).
- *mandating airlines use an increasing percentage of SAF.* This is intended to create a predictable market for SAF, which reduces the risk of investing in capacity to produce SAF.
- *subsidizing the investment in SAF production facilities and/or sales of SAF.* This is intended to reduce the cost and risk of investing in capacity to produce SAF and make SAF less costly/more attractive to airlines. As with other subsidy programs, such subsidies can have significant fiscal cost and should be used with caution.

6 Developing a Green Logistics Plan

Key Messages

- **Governments should conduct a logistics GHG analysis and incorporate climate considerations into the development of their National Logistics Plan to create a Green Logistics Plan. The logistics GHG analysis quantifies the sources of GHG emissions from logistics, analyzes the policy options for mitigating them, and prioritizes them based on development impact, GHG impact, and cost.**
- **The appropriate mix of policy interventions will be different in each country. However, some common near-term actions that governments should consider include:**
  - **addressing framework conditions to withdraw support from and discourage use of fossil fuels**
  - **planning for efficient logistics as part of spatial economic development**
  - **shifting freight movements from road to rail and waterway where those modes can meet transport needs effectively**
  - **optimizing transport operations**
  - **managing vehicle, vessel, and aircraft fleets and improving fuel quality**
- **While wide-scale applications of alternative fuels are unlikely in the short- to medium-term, preparation for a switch to alternative fuels in the long-term should be included in the Green Logistics Planning process (possibly starting with measures for encouraging electrification of LCVs).**

Climate impacts and mitigation policies should be incorporated in each country's overall logistics plan. A Green Logistics Plan would have the following characteristics:

- serves the logistics needs of the country's developing economy, coordinating with the country's economic plans, and recognizing the spatial aspects of its agricultural, mining, industrial, and commercial development
- provides for efficient and low-cost logistics
- makes use of low-emissions modes where economically viable
- phased to take advantage of currently available alternative fuels in the short and medium term and position the country for changes in fuels in the future

This is accomplished by conducting a supply-demand, freight flow, and logistics GHG analysis as part of the country's logistics planning process. A logistics GHG analysis starts with understanding the quantity and sources of logistics GHG emissions in the country. In most countries, the largest source of logistics-related emission, and therefore the focus of mitigation efforts, will be the trucking sector. However, countries with a large oil and gas industry (Russia, Kazakhstan, Turkmenistan) may find that pipelines are the largest source of emissions and a priority for mitigation. Countries with major ports of call for international shipping or airports serving as regional hubs for cargo traffic may need to pay particular attention to those modes.

The second step is to analyze the policy options for reducing logistics GHG emissions. Figure 6.1 outlines a logical process for considering each option. It starts with the framework conditions, and then considers optimization of the logistics system, modal shift, efficiency improvement measures and fuel shift. The usual policy interventions associated with these decarbonization approaches is shown table 6.1. The typical cost and impact on the emissions of the segment are rated (low, medium, high) to help policy makers understand the policy choices and the challenges of implementing them.

Image 6.1. Containers Await the Next Leg of their Journey

Source: Adobe Stock.

Figure 6.1. Analyzing Logistics Decarbonization Options

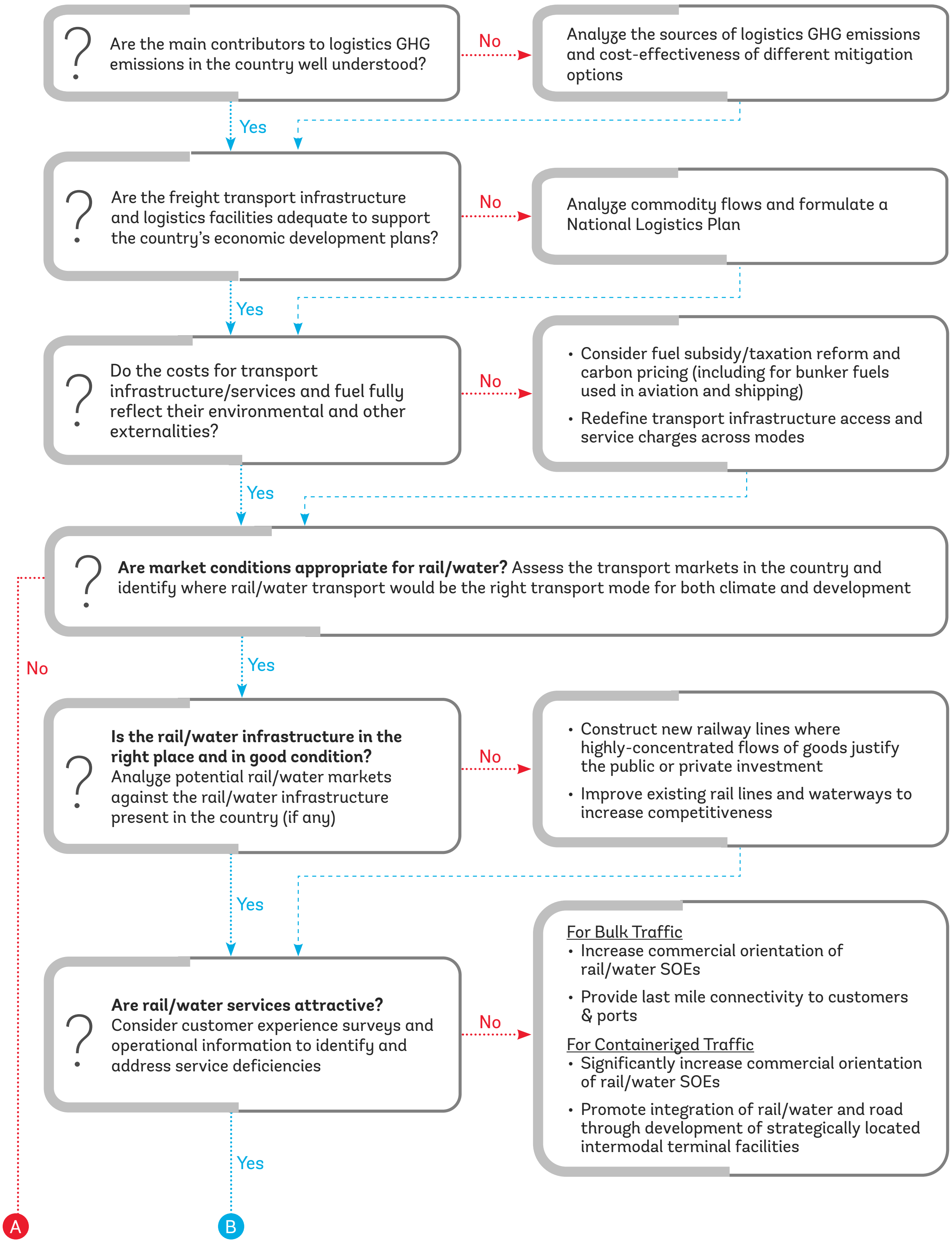
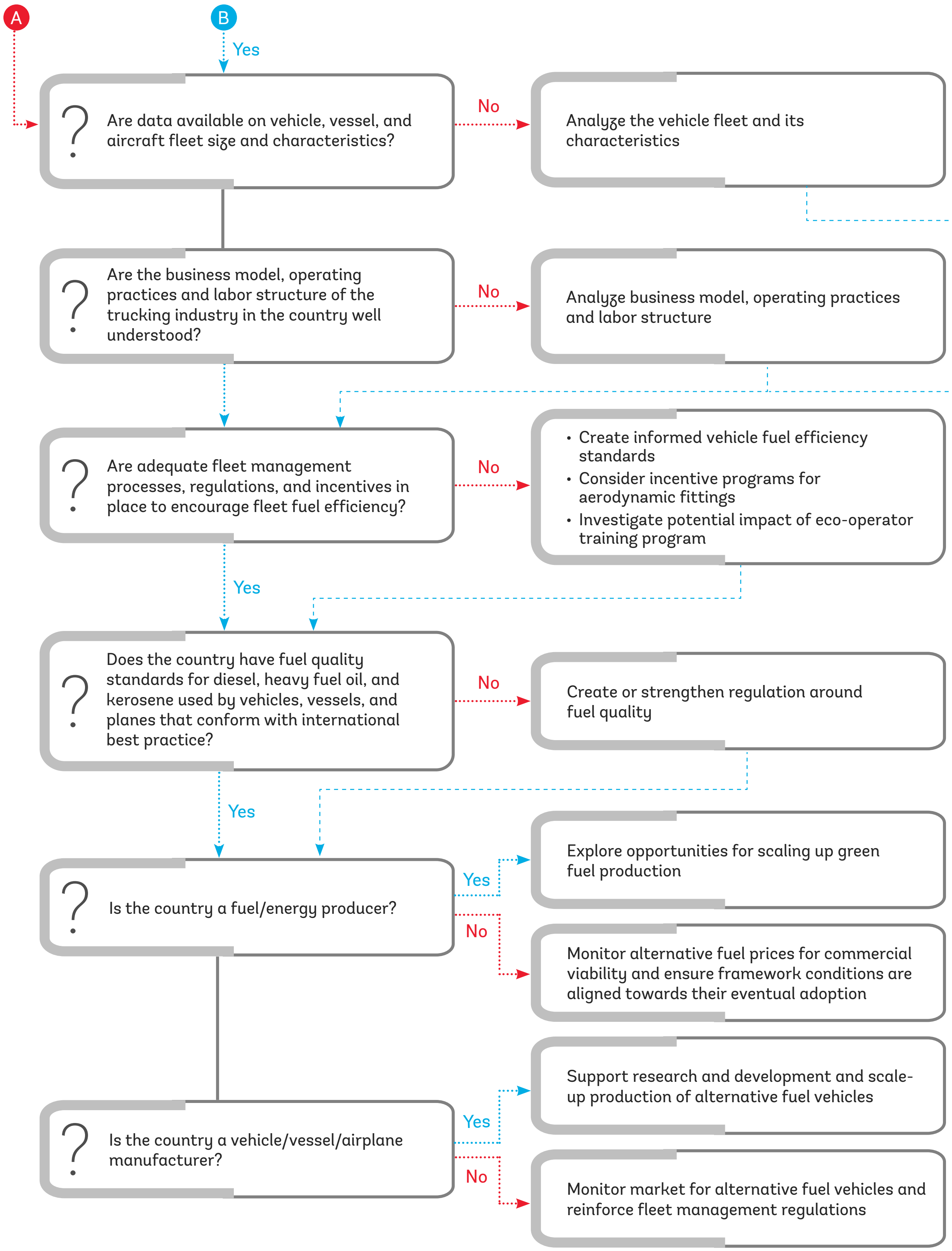


Figure 6.1. Analyzing Logistics Decarbonization Options (Contn.)



Source: Original figure produced for this publication.

Policy interventions can be prioritized considering the development impact, the impact on emissions, and the cost of the intervention. While many of the potential decarbonization measures for freight transport involve regulations and pricing measures that are relatively low cost, others require government support for investment in green infrastructure and technology (table 6.1). A comparison of the cost per ton of GHG reduced will enable governments to prioritize the most cost-effective measures and manage the fiscal requirements of the interventions. These can then be folded into the country's Green Logistics Plan in the same iterative process that other interventions are considered.

The right mix of interventions for reducing logistics GHG emissions will vary in each country. However, some short- to medium- term elements that are likely to be seen in most Green Logistics Plans include:

- framework conditions. All countries may consider establishing framework conditions that phase out financial supports for carbon-based fuels and increasingly discourage their use. For international shipping and air transport, these carbon-pricing measures would need to be coordinated through international organizations to create a consistent pricing framework worldwide.
- planning for efficient logistics. Since efficiently functioning domestic logistics will reduce fuel waste and save GHG emissions, as well as reduce logistics costs, most plans will incorporate measures to improve logistics infrastructure and the functioning of logistics markets.
- mode shift to rail/water transport. Where transport demand is suited to rail or water transport, plans will include improving rail/waterway infrastructure and multimodal transfer facilities and commercializing service provision.
- optimization of operations. Measures to improved vehicle operations (load finding apps, better tires) provide quick wins for both efficiency and climate.
- management of vehicle, vessel, and aircraft fleets and improvement in fuel quality. Measures would include emissions standards, vehicle inspections, and end-of-life programs. Putting in place the processes to manage vehicle, vessel, and airplane fleets and encouraging renewal of older vehicle technologies with more efficient vehicle technologies can help reduce emissions in the near-term, even if the newer vehicles still burn fossil fuels. It can also provide an important regulatory foundation for encouraging the shift to alternative fuels as those vehicle technologies become more commercially available and competitive.

In LMICs, the large-scale adoption of alternative fuels for freight vehicles is not likely to be targeted in the short- to medium-term. While reaching net-zero emissions in logistics will require large-scale adoption of alternative fuels, these fuels and the vehicles that run on them are yet to be deployed at scale for heavy-duty trucks, ships, and cargo planes. Some LMICs with appropriate electricity infrastructure may encourage the adoption of battery-operated light duty trucks. Others, with significant domestic vehicle and fuel/electricity production, can lead the development of alternative fuels and their associated vehicle technologies and scale up their production and distribution of non-fossil fuels and renewable energy.

The World Bank is ready to support countries to conduct a logistics GHG analysis and incorporate it into their national logistics plans.

Table 6.1. Key Solutions and Policies for Decarbonizing Transport

Sector (% of logistics GHGs)	Solution	Policy	Fiscal Cost	Impact	Timing (years)
Framework Conditions	Discourage consumption of carbon-based fuels	• Eliminate subsidies & other supports for carbon-based fuels	Low	High	<5
		• Carbon pricing	Low	High	5-10
Trucking (54%)	Increase fuel efficiency of trucks	• Fuel efficiency standards for truck imports/sales	Low	Medium	<5
	Increase efficiency of truck operations	• Eliminate barriers to filling empty backhauls • Digital platforms development	Low	Medium	<5
	Shift to rail/ inland waterway	• Balance cost recovery among modes/internalize external costs	Low	Low	<5
		• Invest in new infrastructure/ upgrade existing rail & water infrastructure in appropriate markets. Support maintenance expenditure	Medium-High	Medium-High	5-10
		• Strengthen commercial governance of rail & water SOEs	Low	Medium	<5
		• Require logistics facilities to have rail/water connections	Low	Medium	<5
	Electrify trucks in coordination with adequate supply & greening of energy sector	• Ensure adequate electricity supply	Low-High	High	5-10
		• Support establishment of charging infrastructure in urban areas	Medium	High	5-10
		• Subsidize electric trucks	High	High	5-10
		• Monitor developments in technology for medium & heavy trucks to implement technologies as they become established	Low	Low	5-10

Sector (% of logistics GHGs)	Solution	Policy	Fiscal Cost	Impact	Timing (years)
Shipping (25%)	Shift fuels to green hydrogen or ammonia	• Apply carbon tax to carbon-based bunker fuels	Low	High	<5
Warehousing (9%)	Solar power	• Include logistics facilities in programs encouraging rooftop solar	Low	High	<5
	Energy efficiency	• Include logistics facilities in programs to encourage insulation, LED lights, and other energy efficiency measures	Low	Medium	<5
Pipelines (6%)	Regulate methane emissions	• Penalize methane leaks & maintenance releases; monitor pipelines for leaks	Low	High	<5
Aviation (3%)	Shift to sustainable aviation fuels	• Apply carbon tax to traditional aviation fuel (kerosene)	Low	High	<5
		• Mandate use of sustainable aviation fuels	Low	Medium	5-10
		• Subsize investment in sustainable fuel production and/or sales	High	Medium	5-10
Rail (3%)	Electrify traction in coordination with adequate, reliable supply & greening of energy sector	• Support investment in overhead electrification when commercially viable	Medium	Medium	<5
		• Monitor developments in battery and hydrogen traction and plan to implement technologies as they become established	Low	Low	5-10

Source: Original table produced for this publication.

Annex A. Fuels and Their Characteristics

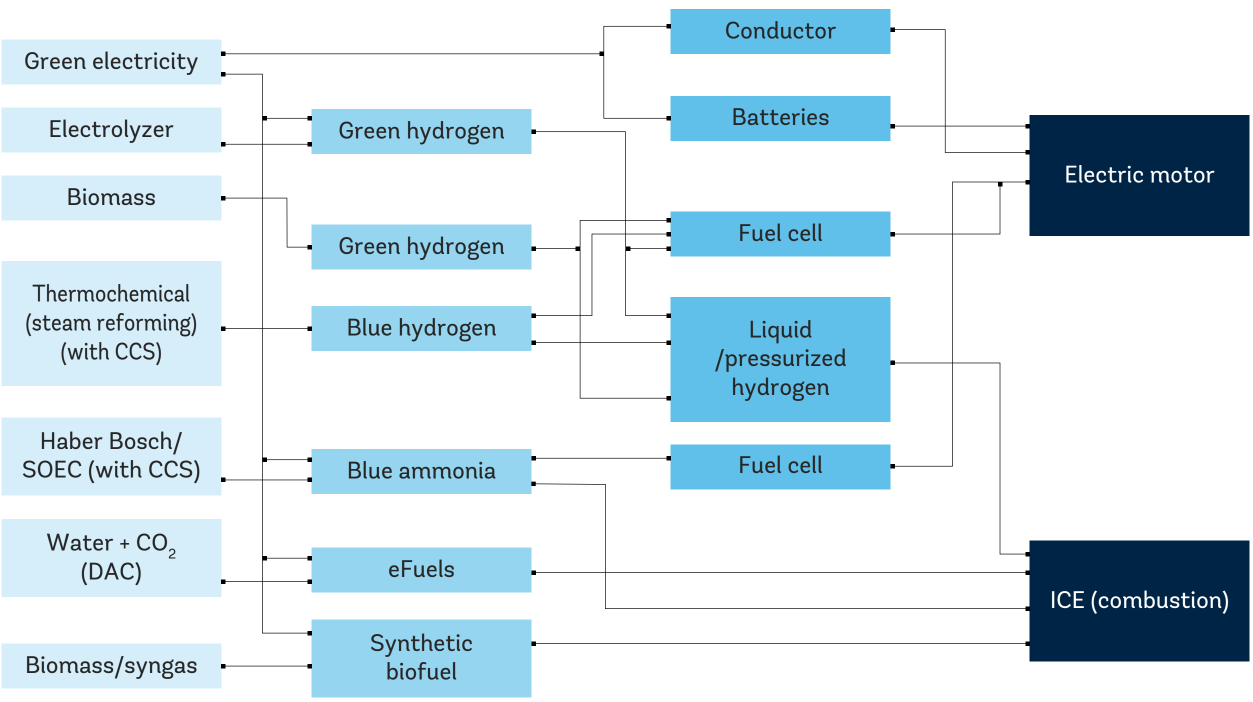
Renewable Fuels and "Green" Energy

Renewable energy is any form of energy from solar, geophysical, or biological sources that is replenished by natural processes at a rate that equals or exceeds its rate of use. It includes low-carbon technologies such as solar energy, hydropower, wind, tides, waves, and ocean thermal energy, as well as renewable fuels such as biomass (IPCC 2011). Nuclear energy is conventionally not considered renewable.

"Green" energy is slightly different. This energy does not emit GHG during either its production or use. It includes hydrogen produced from the electrolysis of water powered by renewable electricity, ammonia produced from green hydrogen, and nitrogen produced using renewable electricity. "Blue" fuels are produced from processes where any GHG is captured, such as CCS, while "grey" fuels is produced by processes where GHG is emitted into the atmosphere. There are other terms in use (for example, turquoise and yellow), which are variants of "green" hydrogen produced using nuclear and solar power. Nuclear energy is considered by some as "green" and by others as not "green." However, it is worth remembering that for the foreseeable future, even if the actual use of the energy does not create GHG, creating and building the associated infrastructure will generate GHG. So almost all "green" fuels are at least a little bit "grey".

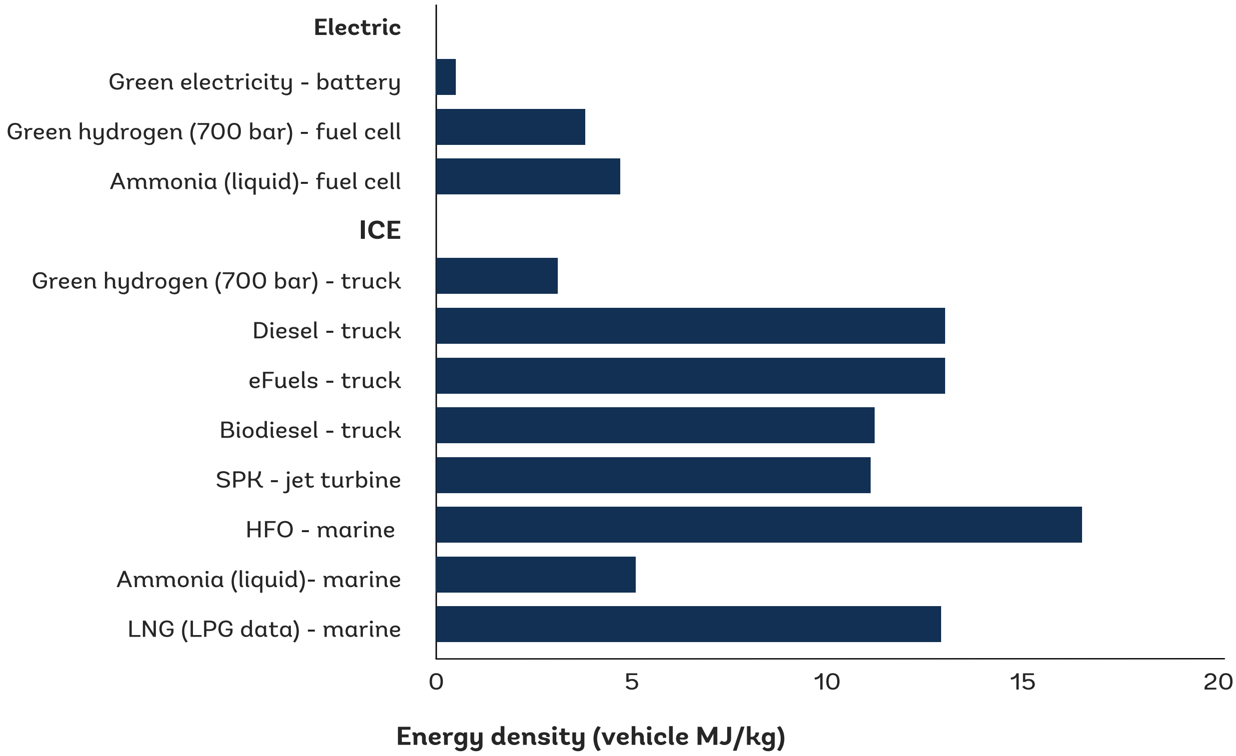
Biofuels include both renewable and non-renewable examples. Where the cultivation of biofuel causes existing vegetation to be removed, or replaces food crops, the consensus is that these are not renewable. When where there are no such impacts, they are considered renewable. eFuels, produced by harvesting CO_2 from the atmosphere using direct air capture are considered renewable but are at an early stage of development.

Figure A.1. Candidate Alternative Fuels



Source: Original figure produced for this publication.

Figure A.2. **Energy Density Delivered to Vehicle (Vehicle MJ per Kg Fuel)**



Source: Original figure produced for this publication.

Biofuels

Biofuels have high energy densities and are typically compatible with existing vehicle fleets and fuel distribution infrastructure. There are three main fuels that are currently commercially available with technically mature production processes:

- Biodiesel. This fuel can be produced from oil crop feedstock, used cooking oil and animal fat wastes. Consumption is most commonly in blended forms from B5 to B20 (the number indicates the percentage share of biodiesel to ordinary diesel), while higher blends, such as B50 or pure biodiesel (B100), can also be used but require modifications to freight vehicles.
- Hydro-treated vegetable oil (HVO). This fuel can be produced from a similar range of feedstocks to biodiesel. It is technically a "drop-in" fuel and can be used unblended (HVO100) without any modifications to diesel engines or fueling infrastructure. However, blends with fossil diesel (for example, 30-50 percent HVO by volume) are currently more commonly used.
- Biomethane. This fuel is similar in its physical and chemical quantities to natural gas and can be used in natural gas-fueled vehicles. Biomethane is produced by the anaerobic digestion of high-moisture-content organic wastes.

Other fuels currently being researched include:

- ED95 ethanol, from conventional crop-based or cellulosic feedstocks
- biofuels from thermochemical production processes, such as gasification and pyrolysis, These processes can produce fuels suitable for use in heavy-duty transport from a range of biomass feedstocks, including forestry and agricultural residues, and municipal solid waste. Syngas produced from gasification can be upgraded to biomethane (BioSNG) (as produced via anaerobic digestion) and a range of other fuels collectively known as biomass-to-liquid (BtL) fuels.
- PtX synthetic fuels combine hydrogen (for example, produced via electrolysis) with carbon or nitrogen to produce gaseous or liquid fuels, including ammonia (from hydrogen and nitrogen).

GHG emissions from biofuels vary considerably depending on the feedstock and precise process used to produce them and, in particular, the extent to which they are calculated on a net or gross basis. Several (such as biodiesel) emit GHG just like conventional diesel does, but the argument is that if they were not converted to biofuel, they would emit GHG naturally or, if grown specifically for conversion to biodiesel, they have absorbed CO_2 from the atmosphere. California has a standard set of emissions,[29] which, for 2021, estimated the GHG emissions from various biofuels on a WTW[30] basis at 25 to 50 percent of that of diesel. However, as electricity is a significant contributor to the GHG emissions from biofuel production, this ratio will vary from country to country. Some biofuels also reduce local air pollution impacts compared to diesel. The cost of the crop-based biofuels is a function of the prices of feedstock, such as soyabeans in the U.S. and sugar in Brazil. The cost of the waste-based biofuels such as HVO is principally related to collection costs. The cost of PtX synthetic fuels is driven by energy costs and they require large-scale green electricity to become a realistic option.

[29] The LCFS (Low Carbon Fuel Standards) which publish annual estimated emissions of various fuels. The EU has a similar set of numbers (the Fuel Quality Directive) which, although not identical, show the same general pattern.

[30] WTW emissions include the net emissions created during the production of the fuel as well as its end-use. Californian electricity averages about 300 gCO_2e/kWh.

References

Abuzo, Anabel A. and Yasunori Muromachi. 2014. "Fuel Economy of Ecodriving Programs: Evaluation of Training and Real-World Driving Applications in Manila, Philippines, and in Tokyo." *Transportation Research Record: Journal of the Transportation Research Board,* 2427. https://doi.org/10.3141/2427-04.

AECOM. 2016. "Eco-Driving for HGVs: Final Report." London: United Kingdom Department for Transport. https://www.fors-online.org.uk/cms/wp-content/uploads/2017/02/Eco-driving-for-HGVs.pdf.

African Development Bank (AfDB). 2010. *Infrastructure Deficit and Opportunities in Africa.* Economic Brief. AfDB, Abidjan, CIV: AfDB. https://www.afdb.org/en/documents/document/economic-brief-infrastructure-deficit-and-opportunities-in-africa-21887.

Al-Alawi, Baha M., Owen MacDonnell, Ross McLane, and Kevin Walkowicz. 2022. *Zeroing in on Zero-Emission Trucks.* CALSTART, Pasadena, CA.

Association of American Railroads. n.d. "Freight Rail: Miles Ahead on Sustainability." https://www.aar.org/article/freight-rail-moving-miles-ahead-on-sustainability/.

Aritua, Bernard. 2019. *The Rail Freight Challenge for Emerging Economies: How to Regain Modal Share.* International Development in Focus. Washington, DC: World Bank. https://openknowledge.worldbank.org/entities/publication/12957f03-7221-543b-beef-b2046b610252.

Asian Development Bank (ADB). 2015. *Improving Energy Efficiency and Reducing Emissions through Intelligent Railway Station Buildings.* Manila, PH: ADB. https://www.adb.org/sites/default/files/publication/173696/energy-intelligent-railway-station.pdf.

Asian Development Bank (ADB). 2016. "Eco-driving to Reduce Freight GHG Emissions in the GMS." *Greater Mekong Region Core Environment Program,* August 23, 2016.

Australian Trucking Association (ATA). 2018. *Truck Impact Chart: Technical Advisory Procedure,* edition 2.2. https://www.truck.net.au/system/files/industry-resources/TAPs%20-%20Truck%20Impact%20Chart%20March%202018.pdf.

Baker, Christopher J. 2014. "A review of train aerodynamics Part 2 – Applications." *The Aeronautical Journal,* 118, 1202. https://doi.org/10.1017/S0001924000009179.

Baker, Peter and Clive Marchant. 2015. "Chapter 9. Reducing the Environmental Impact of Warehousing." *Green Logistics: Improving the Environmental Sustainability of Logistics.* 3rd ed., edited by McKinnon, Alan C., Michael Browne, Maja Piecyk, and Anthony Whiteing, 167–92. London: Kogan Page. https://ftp.idu.ac.id/wp-content/uploads/ebook/ip/GREEN%20LOGISTICS/Green%20Logistics_%20Improving%20the%20Environmental%20Sustainability%20of%20Logistics%20(%20PDFDrive%20).pdf.

Benitez, Daniel Alberto, and Jyoti Bisbey. 2021. *Financing Low Carbon Transport Solutions in Developing Countries.* Transport Decarbonization Investment Series. Washington DC: World Bank. https://hdl.handle.net/10986/36610.

Benitez, Daniel Alberto, and Jyoti Bisbey. 2023. *Financing Climate Action for Transportation in Developing Countries. Washington* DC: World Bank. [publication forthcoming]

Blancas, Luis C., Cecilia Briceño-Garmendia, Hong-Seung Roh, and Huub Vrenken. 2022. *Competing with Logistics Clusters: Vignettes from the International Experience.* Mobility and Transport Connectivity Series. Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/37703.

Boodlal, Leverson, and Ken-Hung Chiang. 2014. *Study of the Impact of a Telematics System on Safety and Fuel-Efficient Driving in Trucks.* Report No. FMCSA-13-020. Washington, DC: US Department of Transportation. https://rosap.ntl.bts.gov/view/dot/177

Bove, Abel, Olivier Hartmann, Aiga Stokenberga, Vincent Vesin, and Yaya Yedan. 2018. *West and Central Africa Trucking Competitiveness.* Africa Transport Policy Program (SSATP) Working paper No. 108. Washington, DC: World Bank. https://www.ssatp.org/publication/west-and-central-africa-trucking-competitiveness.

Central Commission for the Navigation of the Rhine. 2019. *Annual Report 2019: Inland Navigation in Europe, Market Observations.* https://www.ccr-zkr.org/files/documents/om/om19_II_en.pdf.

Clarksons Research Ltd. 2022. *Shipping Intelligence Network.* [Online]. Available at: https://www.clarksons.net/n/#/portal (Accessed: December 2022).

Climate Transparency. 2020. “Climate Transparency Report: Comparing G20 Climate Action and Responses to the COVID-19 Crisis.” https://www.climate-transparency.org/g20-climate-performance/the-climate-transparency-report-2020

Craglia, Matteo. 2022. *Decarbonising Europe’s Trucks: How to Minimise Cost Uncertainty.* International Transport Forum (ITF) Policy Papers No. 107. Paris, France: OECD Publishing. https://www.itf-oecd.org/decarbonising-europes-trucks-minimise-cost-uncertainty.

Das, Saikat. 2016. “Green energy: SBI inks $625 million deal with World Bank.” The Economic Times India, July 2. https://economictimes.indiatimes.com/industry/energy/power/green-energy-sbi-inks-625-million-deal-with-world-bank/articleshow/53020142.cms?from=mdr

Delgado, Oscar, Josh Miller, Ben Sharpe, and Rachel Muncrief. 2016. “Estimating the Fuel Efficiency Technology Potential of Heavy-Duty Trucks in Major Markets around the World.” *Global Fuel Efficiency Initiative (GFEI)* Working Paper No. 14. London, UK: GFEI. https://theicct.org/publication/estimating-the-fuel-efficiency-technology-potential-of-heavy-duty-trucks-in-major-markets-around-the-world/.

Delgado, Oscar. 2016. “Stage 3 China Fuel Consumption Standard for Commercial Heavy-Duty Vehicles.” International Council on Clean Transportation (ICCT) Policy Update, July 8. https://theicct.org/publication/stage-3-china-fuel-consumption-standard-for-commercial-heavy-duty-vehicles/

Dominioni, Goran and Dominik Englert. 2022. *Carbon Revenues from International Shipping: Enabling an Effective and Equitable Energy Transition.* Washington, DC: World Bank. https://openknowledge.worldbank.org/entities/publication/2c6a3435-b005-52a5-89d4-f66e1fe862d2

Dominioni, Goran, Isabelle Rojon, Rico Salgmann, Dominik Englert, Cáit Gleeson, and Sotiria Lagouvardou. 2023. *Distributing Carbon Revenues from Shipping.* © Washington, DC: World Bank. http://hdl.handle.net/10986/39876. License: CC BY 3.0 IGO.

Dundon, Leah A., Craig E. Philip, Madeline C. Allen, and David G. Sehrt. 2021. *Decarbonization of the Inland Waterway Sector in the United States – Pathways and Challenges to a Zero-Carbon Freight Future.* American Bureau of Shipping, Spring, Texas. https://www.iims.org.uk/wp-content/uploads/2021/09/decarbonization-of-the-inland-waterway-sector-in-the-united-states-september-2021.pdf.

Edelstein, Stephen. 2020. "World-first in-road charging test for trucks successful, highway speeds next." Green Car Reports, March 20. https://www.greencarreports.com/news/1127520_world-first-in-road-charging-test-for-trucks-successful-highway-speeds-next.

Energy Transitions Commission (ETC). 2018. "Mission Possible: Reaching net-zero carbon emissions from harder-to-abate sectors by mid-century." Full Report, ETC, London. https://www.energy-transitions.org/publications/mission-possible/.

Englert, Dominik and Andrew Losos. 2021. *Charting a Course for Decarbonizing Maritime Transport: Summary for Policymakers and Industry.* Washington, DC: World Bank. http://hdl.handle.net/10986/35436.

Englert, Dominik, Andrew Losos, Carlo Raucci, and Tristan Smith. 2021. *The Role of LNG in the Transition Toward Low- and Zero-Carbon Shipping.* World Bank, Washington, DC. https://openknowledge.worldbank.org/handle/10986/35437?locale-attribute=en.

Englert, Dominik, Andrew Losos, Carlo Raucci, and Tristan Smith. 2021. *The Potential of Zero-Carbon Bunker Fuels in Developing Countries.* Washington, DC: World Bank. https://openknowledge.worldbank.org/entities/publication/b5697ebf-30cd-5491-8e34-2edb199ae5b7

Eurostat. 2019. *Transport Database for 2019.* https://ec.europa.eu/eurostat/web/transport/data/database.

Eurostat. 2021. "A fifth of road freight kilometres by empty vehicles." https://ec.europa.eu/eurostat/en/web/products-eurostat-news/-/ddn-20211210-1.

Federal Ministry of Transport and Digital Infrastructure (BMVI of Germany). 2019. *Inland Waterway Transport Masterplan.* BMVI, Berlin, Germany. https://bmdv.bund.de/SharedDocs/EN/publications/waterway_transport_masterplan.pdf?__blob=publicationFile.

Financial Express. 2021. "Is demand enough to bring scale for the logistics sector?" Financial Express, June 17. https://www.financialexpress.com/infrastructure/roadways/is-demand-enough-to-bring-scale-for-the-logistics-sector/2272977/

Foster, Vivien, Jennifer Uju Dim, Sebastian Vollmer, and Fan Zhang. 2021. "Understanding Drivers of Decoupling of Global Transport CO_2 Emissions from Economic Growth: Evidence from 145 countries." Policy Research Working Paper No. 9809. World Bank, Washington, DC. https://openknowledge.worldbank.org/handle/10986/36427.

Freight Tiger. 2023. "Our environmental and social solutions create long-term industry shifts that benefit everyone." Accessed April 5. https://www.freighttiger.com/social-impact.

Freis, Julia, Philipp Vohlidka, and Willibald A. Günthner. 2016. "Low-Carbon Warehousing: Examining Impacts of Building and Intra-Logistics Design Options on Energy Demand and the CO_2 Emissions of Logistics Centers." *Sustainability* 8(5): 448. https://doi.org/10.3390/su8050448.

Freitas, Rodrigo Rodrigues de, Márcio de Almeida D'Agosto, and Lino Guimarães Marujo. 2021. "Methodological Proposal for Recognition Systems in Sustainable Freight Transport." *Sustainability* 13 (13): 7511. https://doi.org/10.3390/su13137511.

Fullerton, Garrett F. and C. Tyler Dick. 2015. *Operational Considerations of Transitioning to Emerging Ultra-Low Emission Locomotive Technologies for Heavy-Haul Freight Rail Applications.* Proceedings of the International Heavy Haul Conference, Perth, Australia. https://railtec.illinois.edu/proceedings/operational-considerations-of-transitioning-to-emerging-ultra-low-emission-locomotive-technologies-for-heavy-haul-freight-rail-applications/.

Fuss, Sabine, William F. Lamb, Max W Callaghan,, Jérôme Hilaire, Felix Creutzig, Thorben Amann, Tim Beringer, Wagner de Oliveira Garcia, Jens Hartmann, Tarun Khanna, Gunnar Luderer, Gregory F. Nemet, Joeri Rogelj, Pete Smith, José Luis Vicente Vicente, Jennifer Wilcox, Maria del Mar Zamora Dominguez and Jan C Minx. 2018. *Negative emissions—Part 2: Costs, potentials and side effects.* Environmental Research Letters, 13(6): 063002. www.doi.org/10.1088/1748-9326/aabf9f.

Gibon, Thomas, Álvaro Hahn Menacho, and Mélanie Guiton. 2021. *Life Cycle Assessment of Electricity Generation Options.* United Nations Economic Commission for Europe (UNECE), New York, NY. https://unece.org/sites/default/files/2021-10/LCA-2.pdf.

Global Maritime Energy Efficiency Partnership (GloMEEP). "Shore Power." https://glomeep.imo.org/technology/shore-power/.

Gorham, Roger, Dipan Bose, Maria Cordeiro, Georges Darido, John Koupal, Raman Krishnan, Kazayuki Neki, and Yin Qiu. 2022. *Motorization Management for Development: An Integrated Approach to Improving Vehicles for Sustainable Mobility.* Washington, DC: World Bank. http://hdl.handle.net/10986/37589.

Goswami, Sweta. 2022. "Trucks and buses to comply with fuel consumption standards from April 2023: Govt." Hindustan Times, July 5. https://www.hindustantimes.com/india-news/trucks-and-buses-to-comply-with-fuel-consumption-standards-from-april-2023-govt-101657018439961.html

Grütter, J. M., and L. Dang. 2016. "Eco-Drive: Greater Mekong Sub Region, Phase 2—Green Freight Project Implementation—Lao and Viet Nam." https://www.gms-eoc.org/uploads/resources/251/attachment/Report%20on%20Eco-driver%20training%20Lao%20PDR%20and%20Viet%20Nam%20-%20Grutter%20Consulting%20July%202016.pdf.

Gül, Timur, Laura Cozzi, and Petr Havlik. 2021. *What does net-zero emissions by 2050 mean for bioenergy and land use?* International Energy Agency. https://www.iea.org/articles/what-does-net-zero-emissions-by-2050-mean-for-bioenergy-and-land-use.

Hansson, Julia, Selma Brynolf, Erik Fridell, and Mariliis Lehtveer. 2020. *The Potential Role of Ammonia as a Marine Fuel—Based on Energy Systems Modeling and Multi-Criteria Decision Analysis.* Sustainability, 12(8): 3265. https://doi.org/10.3390/su12083265.

Hileman, James I., Elena De la Rosa Blanco, Philippe A. Bonnefoy, and Nicholas A. Carter. 2013. "The Carbon Dioxide Challenge Facing Aviation." *Progress in Aerospace Sciences* 63 (November):84–95. https://doi.org/10.1016/J.PAEROSCI.2013.07.003.

Hoang, Dung Anh, Yin Yin Lam, Paul Amos, Paul Reddell, Pham Thi Phuong, and Nguyen Thi Phoang Hein. 2019. *Sustainable Development of Inland Waterways Transport in Vietnam: Strengthening the Regulatory, Institutional and Funding Frameworks.* Washington, D.C.: World Bank. http://documents.worldbank.org/curated/en/214851554188572807/Sustainable-Development-of-Inland-Waterways-Transport-in-Vietnam-Strengthening-the-Regulatory-Institutional-and-Funding-Frameworks.

Humphreys, Richard Martin, and Anca Dumitrescu. 2021. "Decarbonizing the Freight and Logistics Sector." Transport Decarbonization Investment Series. World Bank, Washington, DC. https://openknowledge.worldbank.org/handle/10986/36876.

India Planning Commission. 2014. *Total Transport System Study 2014*. [unpublished]

Intergovernmental Panel on Climate Change (IPCC). 2011. *Renewable Energy Sources and Climate Change Mitigation.* Ottmar Edenhofer, Ramón Pichs-Madruga, Youba Sokona, Kristin Seyboth, Patrick Matschoss, Susanne Kadner, Timm Zwickel, Patrick Eickemeier, Gerrit Hansen, Steffen Schloemer, Christoph von Stechow (Eds.) Cambridge, UK: Cambridge University Press. https://www.ipcc.ch/report/renewable-energy-sources-and-climate-change-mitigation/.

International Air Transport Association (IATA). 2019. *Aircraft Technology Roadmap to 2050.* https://www.iata.org/contentassets/8d19e716636a47c184e7221c77563c93/aircraft-technology-net-zero-roadmap.pdf.

International Civil Aviation Organization (ICAO). 2022. *Sustainable Aviation Fuels.* https://www.icao.int/environmental-protection/pages/SAF.aspx

International Council on Clean Transportation (ICCT). 2022. "Stage 3 China Fuel Consumption Standard for Commercial Heavy-Duty Vehicles." *ICCT Policy Update.* Retrieved from ICCT Website: https://theicct.org/publication/stage-3-china-fuel-consumption-standard-for-commercial-heavy-duty-vehicles/.

International Energy Agency (IEA). 2021. *Driving Down Methane Leaks from the Oil and Gas Industry: A Regulatory Roadmap and Toolkit.* Paris, France: IEA. https://www.iea.org/reports/driving-down-methane-leaks-from-the-oil-and-gas-industry

International Energy Agency (IEA). 2022. "Improving the Sustainability of Passenger and Freight Transport."

International Maritime Organization (IMO). 2021. *Fourth IMO Greenhouse Gas Study, 2020.* https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx.

International Renewable Energy Agency (IRENA). 2022. *Renewable Power Generation Costs in 2021.* https://www.irena.org/publications/2022/Jul/Renewable-Power-Generation-Costs-in-2021.

International Transport Forum (ITF). 2017. "ITF Transport Outlook 2017." https://www.itf-oecd.org/transport-outlook-2017.

International Transport Forum (ITF). 2018. *Decarbonising Maritime Transport: Pathways to zero-carbon shipping by 2035.* Paris, FR: OECD Publishing. https://www.itf-oecd.org/sites/default/files/docs/decarbonising-maritime-transport.pdf.

International Transport Forum (ITF). 2019. “ITF Transport Outlook 2019.” OECD, Paris, France. https://www.oecd-ilibrary.org/sites/c013afc7-en/index.html?itemId=/content/component/c013afc7-en.

Janjevic, Milena, Ahmed Al Farisi, Alexis Nsamzinshuti and Alassane Ndiaye. 2018. Chapter 6. “Investigating the Benefits of Shipper-driven Collaboration in Urban Freight Transport and the Effects of Various Gain-sharing Methods.” In *City Logistics 1: New Opportunities and Challenges.* Eiichi Taniguchi and Russel G. Thompson (eds). John Wiley & Sons, Inc. https://doi.org/10.1002/9781119425519.ch6.

Jayathilaka, Ruwan, Chanuka Jayawardhana, Nilupul Embogama, Shalini Jayasooriya, Navodika Karunarathna, Thisara Gamage, and Nethmali Kuruppu. 2022. “Gross domestic product and logistics performance index drive the world trade: A study based on all continents.” PLoS One, 17(3): e0264474. https://doi.org/10.1371/journal.pone.0264474.

Jeffrey, Rebecca. 2022. “SAF remains air cargo’s future fuel focus.” *Aircargo News.* https://www.aircargonews.net/monthly-exclusive/saf-remains-air-cargos-future-fuel-focus/.

Jolly, Jasper. 2021. “UK government backs scheme for motorway cables to power lorries.” The Guardian, Travel and Transport, July 27. https://www.theguardian.com/environment/2021/jul/27/uk-government-backs-scheme-for-motorway-cables-to-power-lorries.

Jones, Robert. 2022. *Decarbonizing Long-haul Trucking.* Ph.D. Dissertation, Department of Chemical Engineering. Massachusetts Institute of Technology, Cambridge, MA.

Kar, Rahul, Philippe A. Bonnefoy, and R. John Hansman. 2010. *Dynamics of Implementation of Mitigating Measures to Reduce CO_2 Emissions from Commercial Aviation.* Report No. ICAT-2010-01. Cambridge, MA: MIT International Center for Air Transportation. https://dspace.mit.edu/bitstream/handle/1721.1/56268/Kar_et_al_ICAT_Report.pdf.

Kharina, Anastasia, Daniel Rutherford, and Mazyar Zeinali. 2016. *Cost Assessment of Near- and Mid-term Technologies to Improve New Aircraft Fuel Efficiency.* Cambridge, MA: International Council on Clean Transportation (ICCT). https://theicct.org/publication/cost-assessment-of-near-and-mid-term-technologies-to-improve-new-aircraft-fuel-efficiency/.

Kok, Irem, Marie Rajon Bernard, Yihao Xie, and Tim Dallmann. 2023. *Accelerating ZEV adoption in fleets to decarbonize road transportation.* ZEV Transition Council Briefing Paper, May. International Council on Clean Transportation (ICCT). https://theicct.org/wp-content/uploads/2023/05/ZEVTC_fleets-briefing_final.pdf.

Krisha, Visakh, Sebastian Stichel, and Saeed Hossein Nia. 2018. Deliverable 4.1. *Development of Functional Requirements for Sustainable and Attractive European Rail Freight: Detailed running gear and wagon design concept.* https://www.diva-portal.org/smash/get/diva2:1421162/FULLTEXT01.pdf.

Lammert, Michael P., Adam Duran, Jeremy Diez, Kevin Burton, and Alex Nicholson. 2014. “Effect of Platooning on Fuel Consumption of Class 8 Vehicles Over a Range of Speeds, Following Distances, and Mass.” *SAE International Journal of Commercial Vehicles,* 7(2). https://www.nrel.gov/docs/fy15osti/62348.pdf.

Lauvaux, Thomas, Clément Giron, Matthieu Mazzolini, Alexandre D'Aspremont, Riley Duren, Daniel Cusworth, Drew Shindell, and Philippe Ciais. 2022. "Global Assessment of Oil and Gas Methane Ultra Emitters." Science, 375(6580): 557-561. https://www.science.org/doi/10.1126/science.abj4351

Lawrence, Martha, and Dick Bullock. 2022. *The Role of Rail in Decarbonizing Transport in Developing Countries.* World Bank, Washington, DC. https://openknowledge.worldbank.org/handle/10986/38214.

Lloyd's Register and UMAS. 2020. *Techno-Economic Assessment of Zero-Carbon Fuels.* https://www.lr.org/en/latest-news/lr-and-umas-publish-techno-economic-assessment-of-zero-carbon-fuels/.

Malina, Robert, Megersa Abera Abate, Charles E. Schlumberger, and Freddy Navarro Pineda. 2022. *The Role of Sustainable Aviation Fuels in Decarbonizing Air Transport.* Mobility and Transport Connectivity Series. Washington, DC: World Bank. http://hdl.handle.net/10986/38171.

McKinnon, Alan C. 2018. "Decarbonizing Logistics: Distributing Goods in a Low Carbon World." Kogan Page, London, UK. https://www.koganpage.com/product/decarbonising-logistics-9780749483807.

McKinnon, Alan C. 2018. *Decarbonizing Logistics: Distributing Goods in a Low Carbon World.* London: Kogan Page. https://www.koganpage.com/product/decarbonising-logistics-9780749483807.

McKinsey & Company. 2020. *Hydrogen-powered aviation: A fact-based study of hydrogen technology, economics, and climate impact by 2050.* Clean Sky 2 Joint Undertaking and Fuel Cells and Hydrogen 2 Joint Undertaking, Belgium. https://www.euractiv.com/wp-content/uploads/sites/2/2020/06/20200507_Hydrogen-Powered-Aviation-report_FINAL-web-ID-8706035.pdf.

Meers, Dries, and Cathy Macharis. 2015. "Prioritization in modal shift: determining a region's most suitable freight flows." *European Transport Research Review,* 7 (23). https://doi.org/10.1007/s12544-015-0172-6.

Meszler, Dan, Oscar Delgado, Felipe Rodriguez, and Rachel Muncrief. 2018. "European HDVs: Cost-effectiveness of Fuel Efficiency Technologies for Long-haul Tractor-Trailers in the 2025-2030 Timeframe." White Paper. The International Council on Clean Transportation (ICCT). https://theicct.org/publication/eu-hdvs-cost-effectiveness-of-fuel-efficiency-technologies-for-long%E2%80%91haul-tractor%E2%80%91trailers-in-the-2025%E2%80%912030-timeframe/.

Motyka, Anna, and Eric Tchouamou Njoya. 2020. Single European Sky: The Progress So Far. *Journal of Aerospace Technology and Management* 12: e3920. https://doi.org/10.5028/jatm.v12.1175

Moul, Andy. 2022. "Six ways to cut emissions in warehousing and distribution." SupplyChainBrain's Think Tank, August 15. https://www.supplychainbrain.com/blogs/1-think-tank/post/33475-green-warehousing-delivering-on-the-business-imperative-of-sustainability

Moynan. 1999. "R&D optimises stainless-steel ore car bodies." *Railway Gazette International,* October 1. https://www.railwaygazette.com/news/randd-optimises-stainless-steel-ore-car-bodies/31393.article.

National Academies of Sciences, Engineering and Medicine (NAS). 2019. *Impacts of Policy-Induced Freight Modal Shifts.* National Cooperative Freight Research Program, Research Report 40. The National Academies Pres, Washington, DC. https://doi.org/10.17226/25660.

National Academies of Sciences, Engineering, and Medicine (NAS). 2016. *Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions.* Washington, DC: The National Academies Press. https://doi.org/10.17226/23490.

National Bureau of Statistics of China. 2020. Table 16-25. "Volume of Freight Handled in Coastal Ports and Inland River Ports by Type of Freight (2019)." In *China Statistical Yearbook 2020.* http://www.stats.gov.cn/sj/ndsj/2020/indexeh.htm.

Niu, Jiqiang, Yang Su, Qiujun Yu, Xialing Cao, and Yanping Yuan. 2020. "Aerodynamics of railway train/tunnel system: A review of recent research." *Energy and Built Environment,* 1 (4): 351–375. https://doi.org/10.1016/j.enbenv.2020.03.003.

Organisation for Economic Co-operation and Development (OECD). 2021. *Update on Recent Progress in Reform of Inefficient Fossil-FUEL Subsidies that Encourage Wasteful Consumption 2021.* https://www.oecd.org/fossil-fuels/publicationsandfurtherreading/OECD-IEA-G20-Fossil-Fuel-Subsidies-Reform-Update-2021.pdf.

Partnership on Sustainable, Low Carbon Transport (SLOCAT). 2022. "Climate Strategies for Transport: An Analysis of Nationally Determined Contributions and Long-Term Strategies October 2022 Update." https://slocat.net/climate-strategies-for-transport/

Pavlenko, Nikita, and Carmen Araujo. 2019. *Opportunities and Risks for Continued Biofuel Expansion in Brazil.* ICCT. https://theicct.org/publication/opportunities-and-risks-for-continued-biofuel-expansion-in-brazil/

Post, Joseph. 2021. The Next Generation Air Transportation System of the United States: Vision, Accomplishments, and Future Directions. *Engineering* 7 (4): 427–30. https://www.engineering.org.cn/en/10.1016/j.eng.2020.05.026.

Programa de Logistica Verde Brasil (PLVB). 2023. "What is PLVB?" https://plvb.org.br/en/what-plvb-is/.

Pye, Steve, James Price, Jennifer Cronin, Isabela Butnar, and Dan Welsby. 2019. *Modelling 'Leadership - Driven' Scenarios of the Global Mitigation Effort.* https://www.theccc.org.uk/publication/modelling-leadership-driven-scenarios-of-the-global-mitigation-effort-ucl-energy-institute/.

Ricardo-AEA. 2015. *Light-weighting as a means of improving heavy-duty vehicles' energy efficiency and overall CO_2 emissions: Heavy-duty vehicles framework contract – service Request 2.* Report for European Commission DG Climate Action, Issue No. 1, March, www.ec.europa.eu/clima/sites/clima/files/transport/vehicles/heavy/docs/hdv_lightweighting_en.pdf.

Sahu, Prasanta K., Agnivesh Pani, and Georgina Santos. 2022. Freight traffic impacts and logistics inefficiencies in India: Policy interventions and solution concepts for sustainable city logistics. *Transportation in Developing Economies,* 8: 31. https://doi.org/10.1007/s40890-022-00161-8

SBB.ch. 2018. "Winter service: so that trains can continue to run despite the snow and ice." November 21. https://sbbcffffs-community.sbb.ch/t5/About-SBB/Winter-service-so-that-trains-can-continue-to-run-despite-the/ba-p/18395.

Shetty, Sangita. 2021. "World Bank to Launch $100 Million Guarantee Scheme for Rooftop Solar Projects." Solar Quarter, March 12. https://solarquarter.com/2021/03/12/world-bank-to-launch-100-million-guarantee-scheme-for-rooftop-solar-projects/.

Smith, Pete, Mercedes Bustamante, et al. 2014. Chapter 11. *Agriculture, forestry and other land use (AFOLU). In Climate Change 2014: Mitigation of Climate Change.* Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (eds Edenhofer O, Pichs-Madruga R, Sokona Y, Farahani E, Kadner S, Seyboth K, Adler A, Baum I, Brunner S, Eickemeier P, Kriemann B, Savolainen J, Schlömer S, von Stechow C, Zwickel T, Minx JC), pp. 811–922. Cambridge University Press, Cambridge, UK and New York, NY, US. https://www.ipcc.ch/report/ar5/wg3/agriculture-forestry-and-other-land-use-afolu/.

Stagl, Jeff. 2017. "Railroads stress better practices, new technologies to cut fuel consumption." *Progressive Railroading.* https://www.progressiverailroading.com/mechanical/article/Railroads-stress-better-practices-new-technologies-to-cut-fuel-consumption--52080.

Taylor, Ian. 2022. "CMA CGM Adopting PSA's Opt-e-Arrive System to Save Fuel and Reduce Emissions." *Bunkerspot*, May 11. https://www.bunkerspot.com/asia/56182-asia-pacific-cma-cgm-adopting-psa-s-opt-e-arrive-system-to-save-fuel-and-reduce-emissions.

Teravaninthorn, Supee and Gaël Raballand. 2009. *Transport Prices and Costs in Africa: A Review of the International Corridors.* Directions in Development, Infrastructure. Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/6610.

Terrazas, Aaron. 2019. "What you need to know about empty miles in trucking." *Convoy*, August 1. https://convoy.com:/blog/empty-miles-in-trucking.

Teter, Jacob, Pierpaolo Cazzola, and Timur Gül. 2017. *The Future of Trucks: Implications for energy and the environment.* Second addition. Paris, France: International Energy Agency (IEA). https://www.iea.org/reports/the-future-of-trucks.

Turner, Julian. 2013. "Resistance is futile: how aerodynamics inform train design." *Journal of Railway Technology* at railway-technology.com, 4 November (Last Updated February 6th, 2020. https://www.railway-technology.com/features/feature-aerodynamic-train-design-arrowedge-union-pacific-bombardier-zefiro/.

Tvinnereim, Endre. 2014. "The bears are right: Why cap-and-trade yields greater emissions reductions than expected, and what that means for climate policy." Climate Change, 127: 447-461. https://doi.org/10.1007/s10584-014-1282-1.

UK Committee on Climate Change. 2018. *Biomass in a low-carbon economy.* https://www.theccc.org.uk/wp-content/uploads/2018/11/Biomass-in-a-low-carbon-economy-CCC-2018.pdf.

UK Department for Transport. 2021. *Final Van Statistics April 2019 – March 2020.* Statistical Release. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1065072/van-statistics-2019-to-2020.pdf.

UK Department for Transport. 2023. "Domestic road freight activity (RFS01)." Statistical data set. https://www.gov.uk/government/statistical-data-sets/rfs01-goods-lifted-and-distance-hauled.

UN Environment Programme (UNEP). 2019. "Addressing the Used Vehicle Market: Potential Strategies for Importing and Exporting Countries to Improve Safety, Fuel Economy, and Emissions Impacts." http://airqualityandmobility.org/PDFs/USED_VEHICLES_WORKING_GROUP_REPORT.pdf.

UN Environment Programme (UNEP). 2020. "Used Vehicles and the Environment: A Global Overview of Used Light Duty Vehicles – Flow, Scale and Regulation." https://wedocs.unep.org/20.500.11822/34175.

United Nations Conference on Trade and Development (UNCTAD). 2018. *Review of Maritime Transport 2018.* https://unctad.org/webflyer/review-maritime-transport-2018.

US Department of Transportation, Bureau of Transportation Statistics. 2022. "US Tonne-Kilometers of Freight." Table 1-50M. https://www.bts.gov/us-tonne-kilometers-freight.

US Department of Transportation, Bureau of Transportation Statistics. 2019. "Commodities on the Mississippi River: 2019." https://www.bts.gov/modes/maritime-and-inland-waterways/commodities-mississippi-river-2019.

US Department of Transportation, Bureau of Transportation Statistics. 2015. *2012 Commodity Flow Survey United States.* https://www.bts.gov/archive/publications/commodity_flow_survey/2012/united_states/index.

Volkswagen Group News. 2020. "First German e-road trial now fully operational." https://www.volkswagenag.com/en/news/2020/08/scania_e_road_trial.html.

Wang, Hui, Jiaying Han, Min Su, Shulin Wan, and Zhenchao Zhang. 2021. "The relationship between freight transport and economic development: A case study of China." Research in Transportation Economics 85: 100885. https://doi.org/10.1016/j.retrec.2020.100885.

Wang, Yang and Alessandra Boggio-Marzet. 2018. "Evaluation of Eco-Driving Training for Fuel Efficiency and Emissions Reduction According to Road Type." *Sustainability*, 10(11): 3891 https://doi.org/10.3390/su10113891.

World Bank Group. 2016. *Guangdong Green Freight Demonstration Project.* Washington, D.C. http://documents.worldbank.org/curated/en/105411467614051818/China-Guangdong-Green-Freight-Demonstration-Project.

World Bank. 2018. "From Parts to Products: Why Trade Logistics Matter." https://www.worldbank.org/en/ news/feature/2018/07/24/from-parts-to-products-why-trade-logistics-matter.

World Bank. 2020. Trading for Development in the Age of Global Value Chains: Trading for Development in the Age of Global Value Chains. World Development Report 2020. Washington, DC: World Bank. https://openknowledge.worldbank.org/entities/publication/e5ffd66c-5de2-57a3-92b0-8c0469880b2a.

World Bank. 2021. Motorization Management and the Trade of Used Vehicles: How Collective Action and Investment Can Help Decarbonize the Global Transport Sector. Transportation Decarbonization Investment (TDI) Series. Washington, DC: World Bank. http://hdl.handle.net/10986/36518.

World Bank. 2022. Carbon Pricing Dashboard. https://carbonpricingdashboard.worldbank.org/map_data.

World Bank. 2023. State and Trends of Carbon Pricing 2023. Washington, DC: World Bank. https://openknowledge.worldbank.org/entities/publication/58f2a409-9bb7-4ee6-899d-be47835c838f.

Yee, R., D. Coleman, and A. Wardrop. 2007. "Optimising the scheduling and operation of trains on a heavy haul railroad." International Heavy Haul Conference, Kiruna, Sweden.

World Bank. 2018. "From Parts to Products: Why Trade Logistics Matter." https://www.worldbank.org/en/news/feature/2018/07/24/from-parts-to-products-why-trade-logistics-matter.

World Bank. 2020. *Trading for Development in the Age of Global Value Chains: Trading for Development in the Age of Global Value Chains.* World Development Report 2020. Washington, DC: World Bank. https://openknowledge.worldbank.org/entities/publication/e5ffd66c-5de2-57a3-92b0-8c0469880b2a.

World Bank. 2021. *Motorization Management and the Trade of Used Vehicles: How Collective Action and Investment Can Help Decarbonize the Global Transport Sector.* Transportation Decarbonization Investment (TDI) Series. Washington, DC: World Bank. http://hdl.handle.net/10986/36518.

World Bank. 2022. *Carbon Pricing Dashboard.* https://carbonpricingdashboard.worldbank.org/map_data.

World Bank. 2023. *State and Trends of Carbon Pricing 2023.* Washington, DC: World Bank. https://openknowledge.worldbank.org/entities/publication/58f2a409-9bb7-4ee6-899d-be47835c838f.

Yee, R., D. Coleman, and A. Wardrop. 2007. "Optimising the scheduling and operation of trains on a heavy haul railroad." International Heavy Haul Conference, Kiruna, Sweden.

Image Credit

Page No.	Source
XII	https://stock.adobe.com/images/container-transportation/85386005
1	https://stock.adobe.com/in/images/container-ship-in-export-and-import-business-and-logistics-shipping-cargo-to-harbor-by-crane-water-transport-international-aerial-view/225978583
7	https://stock.adobe.com/in/images/desert-landscape-arizona-heat-beats-down-on-industrial-building-and-rail-road-track-with-cargo-containers-silo-and-large-facility-in-distance/125234901?prev_url=detail
12	https://stock.adobe.com/in/images/fuel-storage-tanks/194781691?prev_url=detail
14	"Trucks carried by Train in India." Joegoauk (2017) via Flickr. CC BY SA 2.0 https://www.flickr.com/photos/joegoauk73/34596890665/in/photostream/
15	"A train carrying phosphate ore in Saudi Arabia" Saudi Railway Company, SAR (2014) via Wikimedia Commons. CC BY 3.0. https://ar.wikipedia.org/wiki/%D9%85%D9%84%D9%81:SAR_train.jpg
17	"Barge with a load of sand on the Mekong River, Cambodia." gordontour (2023) via Flickr. CC BY NC ND 2.0. https://www.flickr.com/photos/gordontour/52925966609/
24	https://stock.adobe.com/in/images/the-cranes-at-the-docks-and-river/326486791?prev_url=detail
26	"Truck heavily loaded with straw in Morocco." Adobe Stock Image. https://stock.adobe.com/in/images/heavy-loaded-truck-with-straw-in-morocco/215395865
29	"A truck on the national highway heading toward Burkina Faso." Amuzujoe (2019) via Wikimedia Commons. CC BY SA 4.0. https://commons.wikimedia.org/wiki/File:Trailer_Truck_7.jpg
42	USAID West Africa Trade Hub via Flickr. https://flickr.com/photos/57424551@N06/8330529642.
44	https://stock.adobe.com/in/images/black-smoke-from-the-exhaust-pipe-of-a-truck/141233832
55	https://stock.adobe.com/in/images/loading-of-cargo-airplane/372022421?prev_url=detail
57	https://stock.adobe.com/in/images/air-pollution-crisis-in-city-from-diesel-vehicle-exhaust-pipe-on-road/246413648?prev_url=detail
61	https://stock.adobe.com/in/images/bnsf-train-switching-yard-denver-co/414250449
63	https://stock.adobe.com/in/images/container-vagoons-in-export-and-import-business-and-logistics-aerial-view/288509635

WORLD BANK GROUP