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GREEN LOGISTICS: REDUCING CARBON FOOTPRINT IN SUPPLY CHAIN OPERATIONS

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The global logistics sector is the circulatory system of modern commerce, but it is also a major contributor to the climate crisis. Freight transport alone accounts for approximately 8% of global CO_2 emissions, a figure that rises to over 10% when warehousing, packaging, and logistics facilities are included (International Energy Agency [IEA], 2023). With international freight volumes projected to triple by 2050 under business-as-usual scenarios, the urgency to decouple logistics growth from emissions growth has never been greater (International Transport Forum [ITF], 2023). Green logistics—the systematic effort to measure, minimize, and mitigate the environmental impact of logistics operations—has evolved from a niche corporate social responsibility concern into a strategic imperative driven by regulation, investor pressure, and fundamental economic logic.

The Carbon Footprint of Logistics: Understanding the Baseline The logistics carbon footprint is concentrated in transportation. Heavy-duty trucks, which represent only 4% of the global vehicle fleet, are responsible for roughly 40% of road transport CO_2 emissions and 6% of total global emissions (ITF, 2023). Maritime shipping adds a further 2–3% of global emissions—a level that would rank shipping as the sixth-largest national emitter if it were a country—while air cargo, though representing a tiny fraction of freight volume, generates approximately 50 times more CO_2 per ton-kilometer than ocean freight (International Maritime Organization, 2020). Warehousing and logistics facilities contribute additional emissions through energy consumption for heating, cooling, lighting, and material handling equipment.

These figures are not static. The IEA projects that freight transport demand will increase by 150% by 2050 in a baseline scenario, with road freight growing faster than any other mode. Without aggressive intervention, logistics emissions will rise substantially, undermining global climate targets (IEA, 2023). The imperative, therefore, is not merely to improve efficiency at the margin but to fundamentally transform how goods move through supply chains.

Strategic Levers for Decarbonizing Logistics

Modal Shift: From Road and Air to Rail and Water One of the most effective strategies for reducing logistics emissions is shifting freight from high-carbon modes to lower-carbon alternatives. Rail transport produces approximately 76% less CO_2 per ton-kilometer than road transport, while inland waterway transport is similarly efficient (European Environment Agency, 2022). The European Union's Sustainable and Smart Mobility Strategy explicitly targets a substantial increase in rail freight volumes by 2030 and a doubling by 2050, recognizing modal shift as a cornerstone of transport decarbonization (European Commission, 2020).

Multimodal solutions that combine the flexibility of road transport with the efficiency of rail or water are gaining traction. Intermodal terminals that enable seamless transfer between modes, combined with digital platforms that optimize modal selection based on cost, time, and carbon criteria, are making modal shift operationally viable for a broader range of supply chains. Research by McKinnon (2018) emphasizes that the decarbonization potential of modal shift is greatest when accompanied by improvements in rail and waterway infrastructure, electrification of rail lines, and policy frameworks that internalize the external costs of carbon emissions.

Energy Efficiency and Route Optimization While the long-term vision points toward zero-emission vehicles, the most immediately impactful and cost-effective strategies focus on using less energy to move each ton of freight. Route optimization software powered by artificial intelligence can reduce miles traveled and fuel consumed by 5–15% through better sequencing of deliveries, avoidance of congestion, and consolidation of loads (Zavalko, 2018). Eco-driving programs that train drivers in techniques such as smooth acceleration, anticipatory braking, and appropriate speed management have been shown to reduce fuel consumption by 5–10% (Sullman, Dorn, and Niemi, 2015).

Vehicle efficiency technologies also contribute significantly. Aerodynamic improvements—including side skirts, boat tails, and gap fairings—can reduce truck fuel consumption by 5–15% at highway speeds. Low rolling resistance tires improve efficiency by 2–5%. Automatic tire inflation systems maintain optimal pressure, avoiding the efficiency losses and safety risks of underinflated tires (National Renewable Energy Laboratory, 2021). These technologies, while individually modest in their impact, collectively deliver substantial emissions reductions with positive financial returns.

Fleet Electrification and Alternative Fuels The transition from fossil fuels to clean energy represents the most transformative shift in logistics sustainability. Battery-electric vehicles (BEVs) have reached commercial viability for urban and regional delivery applications, with leading logistics operators including DHL, UPS, and Amazon deploying electric vans at scale. For urban delivery routes under 200 kilometers, the total cost of ownership of electric vans is already lower than diesel equivalents when fuel and maintenance savings are fully accounted for (International Council on Clean Transportation, 2022).

For long-haul trucking, the pathway is more complex. Battery-electric heavy trucks face challenges of range, weight, and charging infrastructure. Hydrogen fuel cell vehicles offer longer range and faster refueling but require substantial investment in green hydrogen production and distribution. Biofuels and renewable natural gas provide lower-carbon alternatives that can be used in existing vehicles and infrastructure, serving as bridge solutions while zero-emission technologies mature (ICCT, 2022). The optimal technology mix will vary by geography, duty cycle, and operational requirements.

In maritime shipping, the International Maritime Organization has adopted a target of net-zero greenhouse gas emissions by or around 2050. Alternative fuels—methanol, ammonia, hydrogen, and advanced biofuels—represent the primary decarbonization pathway. Methanol-capable vessels are already in operation, with Maersk leading the deployment of dual-fuel ships (Maersk, 2024). Wind-assisted propulsion technologies, including rotor sails and rigid wings, are being retrofitted to existing vessels as supplementary power sources, reviving a millennia-old propulsion method with modern engineering.

Sustainable Warehousing and Logistics Facilities Warehouses and distribution centers, while representing a smaller share of logistics emissions than transportation, offer substantial abatement opportunities with attractive economics. Sustainable warehouse design incorporates solar photovoltaic panels, which can transform warehouse rooftops from idle space into energy-generating assets. LED lighting with motion sensors reduces electricity consumption by 50–80% compared to conventional lighting. Natural ventilation and daylighting, where climate and building design permit, eliminate mechanical heating and cooling loads. High-efficiency HVAC systems, often using heat pump technology, further reduce energy consumption (Baker and Marchant, 2020).

Building certification under LEED (Leadership in Energy and Environmental Design) or BREEAM (Building Research Establishment Environmental Assessment Method) provides third-party validation of environmental performance and increasingly influences tenant and investor decisions. Location decisions also matter: warehouses positioned close to customers reduce last-mile transport distances and emissions, a principle that has driven the proliferation of urban micro-fulfillment centers (Dablanc et al., 2017).

Packaging Optimization and Waste Reduction Packaging is integral to logistics but generates enormous waste and embodied carbon. E-commerce has exacerbated the problem, with products shipped in oversized boxes filled with plastic cushioning that is difficult to recycle. Sustainable packaging strategies include right-sizing boxes to eliminate void fill and reduce dimensional weight charges from carriers, replacing plastic cushioning with paper-based alternatives, designing packaging for recyclability using mono-materials rather than multi-layer laminates, and developing reusable packaging systems (Accorsi, Cascini, and Manzini, 2020).

Several logistics providers and retailers are piloting reusable packaging solutions for e-commerce, where customers return empty packaging for cleaning and reuse. While operational complexity and reverse logistics costs remain barriers, regulatory pressure—including extended producer responsibility legislation in the European Union and several U.S. states—is driving adoption.

Circular Economy and Reverse Logistics Green logistics extends beyond forward distribution to encompass reverse logistics—the movement of goods from customers back through the supply chain for returns, repair, remanufacturing, or recycling. Efficient reverse logistics recovers value from products that would otherwise be discarded, reduces demand for virgin materials, and builds customer loyalty through convenient returns processes. In the European Union, the Circular Economy Action Plan explicitly links logistics to circularity, promoting product-as-a-service models where manufacturers retain ownership and responsibility for products throughout their lifecycle (European Commission, 2020).

Circular logistics models fundamentally reshape logistics flows, creating continuous cycles of delivery, return, and refurbishment rather than linear take-make-dispose patterns. These models offer both environmental benefits and new revenue opportunities, though they require sophisticated reverse logistics capabilities that many organizations have yet to develop.

Collaboration and Supply Chain Integration Many of the most substantial emissions reduction opportunities in logistics cannot be realized by any single organization acting alone. Horizontal collaboration—where multiple shippers share transport capacity—reduces empty miles and improves vehicle utilization. Vertical collaboration—where supply chain partners share data and coordinate operations—enables better planning, reduced buffer inventories, and more efficient logistics networks.

Digital platforms that connect shippers with carriers in real time are reducing the fragmentation that has historically led to inefficient asset utilization. Research by van Loon et al. (2020) demonstrates that collaborative logistics models can reduce emissions by 10–30% through improved vehicle fill rates and reduced empty running, while simultaneously reducing costs for participants.

Measuring and Reporting Logistics Emissions Credible sustainability requires credible measurement. The Global Logistics Emissions Council (GLEC) Framework, developed by the Smart Freight Centre, provides a standardized methodology for calculating logistics emissions across modes, enabling consistent reporting and comparison (Smart Freight Centre, 2023). The framework covers Scope 1 emissions (direct emissions from owned or controlled sources), Scope 2 emissions (indirect emissions from purchased electricity), and Scope 3 emissions (all other indirect emissions in the value chain), aligned with the Greenhouse Gas Protocol.

Digital technologies are transforming emissions measurement. Telematics data provides actual fuel consumption rather than modeled estimates, replacing the generalized emission factors that have historically been the basis of carbon accounting. Internet of Things sensors monitor energy use in warehouses. Blockchain platforms enable verification of emissions data across multi-party supply chains. These technologies support regulatory compliance, customer reporting, and the identification of emissions reduction opportunities.

Challenges and the Path Forward The transition to green logistics faces substantial obstacles. The capital requirements for fleet electrification, alternative fuel infrastructure, and sustainable facility construction are significant. Small and medium-sized logistics enterprises, which constitute the majority of the industry, often lack the financial resources and technical expertise to invest in sustainability.

Technology uncertainty—particularly for long-haul trucking and maritime shipping—creates risk for organizations that invest heavily in a technology that may not become the dominant standard (McKinnon, 2018).

Policy frameworks are essential to overcoming these barriers. Carbon pricing, whether through taxes or emissions trading systems, internalizes the external costs of emissions and creates economic incentives for decarbonization. Vehicle emission standards, low-emission zones in cities, and mandates for zero-emission vehicle sales provide regulatory certainty that encourages investment. Public investment in charging and refueling infrastructure addresses the chicken-and-egg problem that has slowed the adoption of alternative fuel vehicles.

Despite the challenges, the direction of travel is unmistakable. Green logistics is no longer a niche pursuit but a central strategic priority for the industry. The organizations that lead in this transition—investing in the technologies, processes, and capabilities that define sustainable supply chains—will be positioned to thrive in a world where carbon constraints are tightening and stakeholder expectations are rising. The greening of logistics is not merely an environmental imperative; it is the next frontier of competitive advantage in global commerce.

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THE IMPLEMENTATION OF GREEN LOGISTICS PRINCIPLES IN UKRAINE'S TRANSPORT SYSTEM

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One of the main environmental problems facing Ukrainian cities is air pollution caused by transport. The greatest threat comes from old cars and vehicles with diesel engines, which emit nitrogen oxides, carbon monoxide, soot and other toxic substances. The situation is exacerbated by poor-quality fuel, an overburdened transport network and underdeveloped public transport, which leads to an increase in the use of private cars.

The biggest source of air pollution is exhaust fumes from internal combustion engines. These contain over 100 toxic substances, including carbon monoxide, nitrogen oxides, volatile organic compounds, soot and sulphur oxides. The main causes of high pollution levels are the growing number of private cars, the use of an outdated vehicle fleet, the use of low-quality fuel and the poor state of the road infrastructure.

Road transport has a significant negative impact on the environment and public health. High concentrations of traffic are found in large cities and industrial regions, where pollutants accumulate directly in the lower layers of the atmosphere. In addition to air pollution, transport emissions contribute to the greenhouse effect and global climate change.

The situation in Ukraine is further complicated by the consequences of military action, which has led to the destruction of roads, bridges and transport infrastructure. Rebuilding this infrastructure presents a unique opportunity to integrate "green" corridors and smart traffic management systems from the ground up. This has a negative impact on logistics processes, increases transport costs and hinders transport links between regions.