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Sustainable Logistics and Competitiveness: Strategies for Reducing Costs and Impact Environmental in Road Transport

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Summary

Road logistics is the primary mode of freight transportation in Brazil and much of the world, playing a vital role in the economy but also accounting for high operating costs and significant environmental impacts. This article analyzes the relationship between sustainable logistics practices and business competitiveness, highlighting strategies to reduce costs and minimize the environmental impacts of road transport. Studies by renowned authors such as Ballou (2006), Bowersox and Closs (2014), and Rodrigue (2020) were used, as well as reports from the International Energy Agency (IEA, 2019) and the Organization for Economic Cooperation and Development (OECD, 2020). The research demonstrates that sustainable practices, such as fleet renewal, the use of alternative fuels, smart routing, and technological integration, contribute not only to reducing pollutant emissions but also to increasing companies' efficiency and competitiveness in the market. The results indicate that sustainability, far from being merely an additional cost, can become a competitive differentiator in the contemporary logistics sector.

Keywords: Sustainable Logistics; Road Transport; Competitiveness; Costs; Environment.

Abstract

Road logistics is the main means of freight transport in Brazil and in much of the world, playing an essential role in the economy but also being responsible for high operational costs and significant environmental impacts. This article aims to analyze the relationship between sustainable logistics practices and business competitiveness, highlighting strategies to reduce costs and minimize the environmental effects of road transport. Studies by renowned authors

such as Ballou (2006), Bowersox and Closs (2014), and Rodrigue (2020), as well as reports from the International Energy Agency (IEA, 2019) and the Organization for Economic Cooperation and Development (OECD, 2020), were used. The research shows that sustainable practices, such as fleet renewal, use of alternative fuels, smart routing, and technological integration, contribute not only to reducing pollutant emissions but also to increasing efficiency and competitiveness of companies in the market. The results indicate that sustainability, far from being just an additional cost, can be configured as a competitive differential in the contemporary logistics sect

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1. Introduction to Sustainable Logistics and Road Transport

Sustainable logistics emerges as a response to growing global concerns about the environmental and social impacts of transportation activities, especially in the road mode. In Brazil, this mode accounts for approximately 65% of the entire freight transportation matrix, according to the National Transportation Confederation (CNT, 2021), revealing its strategic importance and, at the same time, its challenges regarding fossil fuel consumption and greenhouse gas emissions. According to Ballou (2006), logistics should be understood not only as a set of processes focused on operational efficiency, but as an essential link in competitiveness and meeting social demands. Therefore, it is essential to align logistics practices with the sustainability agenda, since reducing environmental impact is directly linked to companies' corporate image and competitive positioning in the market.

Road transportation is a highly energy-intensive sector, representing one of the largest emitters of carbon dioxide in Brazil and worldwide. According to the International Energy Agency (IEA, 2019), the transportation sector accounts for approximately 24% of global COÿ emissions, with heavy-duty vehicles accounting for almost half of this total. These data reinforce the need to rethink transportation models, considering alternatives that minimize environmental damage while also offering economic viability for companies. As Rodrigue (2020) emphasizes, logistics sustainability should not be seen as an additional burden, but as a strategic investment that guarantees efficiency gains in the medium and long term, increasing the sector's competitiveness.

Another aspect that strengthens the discussion on sustainable logistics is linked to regulatory pressure and civil society engagement. In several regions of the world, especially in the European Union, legislation has been requiring stricter vehicle emissions standards and corporate social and environmental responsibility (OECD, 2020). In Brazil, public policies such as the Motor Vehicle Air Pollution Control Program (PROCONVE) are already showing progress, albeit limited. Such regulations require changes in practices.

business and demand constant technological innovation, which, according to Porter and Van der Linde (1995), can generate “compensatory innovations”, in which the adoption of cleaner technologies also leads to cost reductions and efficiency gains.

Beyond regulatory issues, there is a growing consumer movement toward brands and companies committed to sustainable practices. The Nielsen report (2019) indicates that more than 70% of global consumers prefer to purchase products and services from companies that demonstrate social and environmental responsibility. In the logistics sector, this trend is reflected in the demand for more transparent and responsible supply chains, in which emission reduction and energy efficiency become competitive differentiators. This reinforces the vision of Elkington (1998), who coined the concept of the "triple bottom line," arguing that corporate performance should be evaluated from three dimensions: economic, social, and environmental.

It is also important to highlight the intrinsic relationship between sustainability and logistics costs. Traditionally, the road sector is seen as costly due to its high fuel consumption and dependence on the road network. However, recent studies have shown that sustainable practices, such as smart routing and the use of tracking technologies, significantly reduce waste and increase productivity (Bowersox; Closs, 2014).
Operational efficiency, therefore, is no longer limited to simply cutting costs, but to the adoption of practices that harmonize competitiveness and environmental responsibility.

Another crucial factor is the road sector's vulnerability to variable costs, such as the price of diesel, which in Brazil fluctuates significantly due to geopolitical and economic factors. The National Land Transportation Agency (ANTT, 2020) indicates that fuel can represent up to 40% of a truck's operating costs. In this scenario, sustainable practices such as the use of biofuels, natural gas for vehicles, and fleet electrification prove to be alternatives not only for reducing environmental impacts but also for increasing predictability and cost stability. As Sachs (2015) notes, the energy transition is one of the keys to reconciling economic development and environmental preservation in the 21st century.

The introduction of sustainable logistics into the business debate also finds support in more comprehensive performance metrics. Currently, analyzing indicators such as carbon footprint, energy intensity, and total vehicle ownership costs have become indispensable tools for logistics managers. As Christopher (2016) points out, contemporary logistics must be understood as an integrated system that balances efficiency, resilience, and social and environmental responsibility. Thus, sustainability is not just a trend, but a requirement for organizations' survival in increasingly competitive and regulated markets.

Finally, it's worth emphasizing that logistics sustainability shouldn't be analyzed solely from a business perspective, but as a state policy and a collective responsibility. Sustainable road transportation is a systemic challenge that involves adequate infrastructure, incentives, and

government initiatives, technological innovation, and the engagement of businesses and society. According to Veiga (2010), sustainable development is that which meets the needs of the present without compromising the ability of future generations to meet their own. Therefore, introducing sustainability into road transportation means not only reducing costs and immediate impacts, but also building a more equitable and lasting development model.

2. Business Competitiveness and Sustainability in Logistics

Competitiveness in the logistics sector, especially in the road transport sector, depends on factors that go beyond simple operational efficiency. The incorporation of sustainable practices has proven to be a strategic differentiator for companies seeking not only to survive but also to lead in increasingly demanding markets. According to Porter and Kramer (2006), companies must align their corporate social responsibility strategies with the creation of shared value, so that sustainability is not seen as a cost, but as an investment in competitiveness. In this sense, the adoption of clean technologies, fleet modernization, and the digitalization of logistics processes not only reduce environmental impacts but also provide productivity gains and credibility with customers and investors.

Road transport, historically associated with high levels of pollution and waste, has reinvented itself through sustainability as a driver of innovation and competitive advantage. Companies that adopt energy-efficient practices, such as hybrid or electric vehicles, reduce maintenance and fuel costs, while also benefiting from a positive image among increasingly conscious consumers. Studies by Goldsby and Martichenko (2005) indicate that lean logistics, when combined with sustainability principles, provides more agile, cost-effective, and environmentally responsible supply chains, which strengthens competitiveness in highly competitive sectors.

The relationship between competitiveness and sustainability is also reflected in companies' ability to meet the demands of international partners. In global supply chains, environmental certifications such as ISO 14001 have become requirements for Permanence in developed markets, especially the European Union. This means that Brazilian companies that fail to adapt their logistics practices may lose competitive ground due to a lack of regulatory compliance. As Sachs (2015) points out, sustainability is no longer optional and has become a determining factor for the integration of economies in an interdependent and globalized world.

Another relevant aspect is the risk reduction afforded by adopting sustainable practices. In a context of increasing climate instability, companies that invest in more efficient and less polluting fleets are less exposed to future restrictions.

legal constraints or pressure from stakeholders. According to Hart and Milstein (2004), organizations that incorporate sustainability into their strategy are able not only to mitigate risks but also to explore new market opportunities, especially in the clean energy and sustainable mobility sectors. This enhances their competitive advantage over competitors that still operate under outdated and environmentally unsustainable models.

From an economic perspective, sustainability in road logistics is also associated with efficient resource use. Companies that use advanced routing technologies, telemetry, and fleet management systems can reduce fuel consumption, travel time, and maintenance costs. Studies by Bowersox and Closs (2014) demonstrate that the use of information and communication technologies in road transport can generate reductions of up to 20% in logistics costs, in addition to significantly contributing to the reduction of COÿ emissions. This synergy between sustainability and efficiency proves that modern competitiveness requires more than low prices: it requires strategic intelligence and social and environmental responsibility.

Furthermore, incorporating sustainability into the logistics sector has a direct impact on attracting investment. Increasingly, international funds and development banks are directing resources to projects that meet ESG (Environmental, Social, and Governance) criteria. The PwC report (2020) highlights that, by 2025, more than half of the assets managed globally will be under strategies aligned with ESG principles. This means that logistics companies that fail to demonstrate a commitment to reducing environmental impacts may encounter barriers to accessing capital, compromising their competitiveness. Conversely, those that lead the sustainable transition will have greater ease in raising funds and expanding their operations.

It is also worth noting that business competitiveness should not be analyzed solely from a cost perspective, but also from a reputational perspective. In an age of digital media and information transparency, unsustainable practices are quickly exposed and can generate image crises with severe consequences. Kotler and Keller (2012) state that building brand equity depends on a company's perception of social and environmental responsibility, with reputation being one of the most valuable assets in the contemporary economy. In the logistics sector, companies that adopt sustainable practices create market advantages that cannot be easily replicated by competitors.

Finally, it's essential to understand that integrating competitiveness and sustainability requires a cultural shift within companies. It's not just about investing in technology or cleaner processes, but about developing an organizational mindset focused on the long term and shared value. According to Drucker (1986), "organizations must seek results that transcend immediate gains and contribute to society as a whole."

Therefore, business competitiveness in road transport will only be fully achieved if it is based on practices that reconcile economic efficiency, environmental responsibility and social commitment.

3. Environmental Impacts of Road Transport and Mitigation Strategies

Road transport is recognized as one of the economic activities with the greatest environmental impact, especially due to its almost exclusive dependence on fossil fuels.
According to the International Energy Agency (IEA, 2019), road transport vehicles are responsible for approximately 18% of global COÿ emissions, particularly heavy trucks, which consume a lot of energy. In Brazil, data from the National Observatory of Transport and Logistics (ONTL, 2020) indicate that more than 90% of the fleet still relies on diesel as its primary fuel, which increases environmental impacts by including not only greenhouse gases but also local pollutants such as nitrogen oxides (NOx) and particulate matter. The World Health Organization (WHO, 2018) warns that these pollutants are directly linked to respiratory and cardiovascular problems in urban populations, reinforcing the urgency of environmental mitigation in the logistics sector.

Mitigation strategies have been increasingly discussed in research and technical reports, with emphasis on the use of biofuels, compressed natural gas (NGV), and fleet electrification. Studies by Goldemberg (2010) indicate that Brazil has comparative advantages in the use of biofuels, especially biodiesel and ethanol, due to its relatively clean energy matrix. However, its large-scale adoption faces infrastructure barriers and initial costs. According to BNDES (2021), vehicle electrification in the freight transportation sector, although still in its infancy, has great potential for expansion with tax incentives and investments in charging infrastructure. The challenge is to balance technological innovation, economic viability, and environmental impact to reduce the negative externalities of road transportation.

One of the solutions gaining prominence is the adoption of green logistics, a concept that involves integrating environmental practices into all stages of the supply chain. Sarkis (2003) defines green logistics as a set of practices aimed at reducing environmental impacts through optimized transportation, waste management, recycling, and the use of clean technologies.
In Brazil, companies such as Ambev and Natura have already adopted reverse logistics initiatives, in which packaging and waste are returned to the production cycle, contributing not only to sustainability but also to compliance with environmental legislation such as the National Solid Waste Policy (Law No. 12,305/2010). Such practices strengthen the relationship between logistics and social and environmental responsibility, in addition to reducing long-term costs by reusing materials and optimizing processes.

Another mitigation strategy is the use of information technology to optimize routes, which has a direct impact on reducing fuel consumption and COÿ emissions. According to Bowersox and Closs (2014), intelligent routing can generate fuel savings of up to 15% and significantly reduce logistics costs. In Brazil, transportation companies have been adopting telemetry systems and fleet management software that allow them to monitor vehicle performance in real time, avoiding unnecessary trips and

encouraging economical driving practices. This movement demonstrates how digital innovation can be combined with sustainability, reinforcing the importance of technological transformation in the sector.

Furthermore, preventive vehicle maintenance is essential for reducing emissions and fuel consumption. Studies by Christopher (2016) highlight that trucks with regular maintenance emit up to 25% fewer pollutants than vehicles in poor mechanical condition. This data reinforces the need for ongoing training for drivers and fleet managers, since efficient driving and preventive equipment control are crucial for achieving positive environmental results. Promoting courses and training on sustainable driving is a strategy that combines environmental responsibility with operational efficiency, promoting economies of scale.

Another dimension of the environmental impacts of road transport concerns noise pollution and the degradation of road infrastructure. According to studies by Rodrigue (2020), noise generated by heavy vehicles directly affects the quality of life in urban areas, while heavy traffic accelerates road deterioration, requiring continuous investment in maintenance.
These effects, although less discussed than greenhouse gas emissions, represent high social costs and must be considered in public policies for sustainable mobility. In this context, the integration of logistics and urban planning is essential to mitigate negative externalities and create more balanced solutions for freight transportation.

The use of alternative propulsion technologies, such as green hydrogen, has been explored as a long-term solution to the environmental impacts of road transport. Studies by the International Renewable Energy Agency (IRENA, 2020) indicate that hydrogen can reduce emissions from the sector by up to 70%, provided its production is based on renewable sources.
Although it still faces economic and technological barriers, hydrogen holds promise for the future of sustainable logistics, especially in high-demand transportation corridors. This perspective reinforces the importance of continuous innovation and investment in research and development (R&D) to advance environmental solutions in the sector.

In short, the environmental impacts of road transportation represent one of the greatest contemporary challenges for logistics. Mitigating these externalities requires a set of strategies ranging from the adoption of alternative fuels to the integration of digital technology and preventive management. According to Veiga (2010), sustainability must be understood as a dynamic and multidimensional process that requires innovation, planning, and cooperation between the government, businesses, and society. Thus, environmental mitigation strategies not only reduce costs and risks but also create opportunities for competitiveness in globalized markets that value responsible practices.

4. Technological Innovation and Sustainability in Road Transport

Technological innovation is one of the fundamental pillars for advancing sustainability in road transportation, acting as a driver for transforming logistics and business practices. According to Schumpeter (1984), innovation is the central element of economic development, enabling the renewal of entire sectors through new products, processes, and organizational structures. In the logistics context, the adoption of clean and digital technologies is the most viable path to reconciling efficiency, competitiveness, and environmental responsibility. This requires robust investment in research and development (R&D), as well as public policies that encourage fleet modernization and supply chain digitalization.

One of the most discussed innovations is the electrification of fleets, which, although still limited in emerging countries, represents an irreversible trend in developed markets. According to BloombergNEF (2021), more than half of commercial vehicles sold globally are expected to be electric by 2040. This transition, however, requires strong charging infrastructure and tax incentives to overcome the high initial costs. In Brazil, initiatives such as Rota 2030, which encourages energy efficiency and innovation in the automotive sector, indicate important but insufficient steps in the face of climate urgency. As Sachs (2015) observes, the transition to a low-carbon economy is a civilizational challenge that requires cooperation between businesses, governments, and society.

In addition to electrification, the digitalization of logistics also represents a disruptive innovation for sustainability. Technologies such as artificial intelligence, big data, and the Internet of Things (IoT) allow real-time monitoring of fleet performance, route optimization, and prediction of mechanical failures, reducing costs and emissions. Studies by Waller and Fawcett (2013) demonstrate that the use of big data analytics in transportation can reduce operating costs by up to 20% and carbon emissions by 15%. These advances demonstrate that sustainability is not dissociated from technological innovation, but is strengthened by it, creating new standards of competitiveness in the logistics sector.

Automation and autonomous vehicles are another technological frontier that promises to revolutionize road transportation. Research by Rodrigue (2020) indicates that automation can significantly reduce fuel consumption by adopting more efficient and consistent driving patterns. Furthermore, autonomous vehicles reduce labor costs and increase road safety, factors that are linked to business competitiveness. However, regulatory and ethical challenges remain significant, requiring broad social discussion about the impacts of this innovation on the labor market and public safety.

Another relevant aspect is the integration of technological innovation with circular economy practices. Transportation companies have been investing in recycled tires, parts reuse, and reverse logistics systems to reduce waste generation and extend the useful life of their assets.

According to the Ellen MacArthur Foundation (2019), the circular economy applied to the transportation sector could generate savings of up to US$1 trillion per year globally, in addition to drastically reducing environmental impacts. This integration of technology and circularity strengthens the systemic vision of sustainable logistics, which seeks to align economic growth with environmental responsibility.

Technological innovation also plays a strategic role in reducing accidents and improving road safety. Advanced driver assistance systems, such as automatic emergency braking and electronic stability control, reduce risks and contribute to lowering the social costs associated with traffic accidents. According to data from the World Health Organization (WHO, 2018), road accidents are one of the leading causes of death in developing countries, and their reduction is directly linked to the technological modernization of vehicle fleets.
Therefore, investing in innovation is not just a question of efficiency, but of social and public responsibility.

Another key focus is collaboration between technology companies, universities, and the government to accelerate innovation in road transportation. Open innovation models, championed by Chesbrough (2003), allow for knowledge sharing and reduced research costs, increasing the speed of technological transformations. In Brazil, partnerships between automakers, mobility startups, and academic institutions have been generating innovative solutions in areas such as alternative fuels, telemetry, and integrated management systems. These collaborations demonstrate that technological innovation cannot be isolated, but must be built within collaborative ecosystems that align public and private interests.

Finally, it is essential to understand that technological innovation is not an end in itself, but a means to achieve more sustainable, efficient, and competitive road transportation. As Freeman and Soete (1997) point out, innovation only becomes meaningful when applied to concrete societal and market problems. Therefore, technologies applied to logistics must prioritize reducing environmental impacts, improving operational efficiency, and promoting social well-being. Thus, technological innovation establishes itself as an indispensable driver for the future of sustainable logistics, aligning economic growth with global climate mitigation goals.

5. Business Competitiveness and Sustainability in Road Logistics

The pursuit of corporate competitiveness in the transportation sector is increasingly linked to the adoption of sustainable practices. In the past, reducing costs and increasing efficiency were considered the only ways to remain competitive, but today, companies that ignore the environmental agenda suffer from loss of reputation and reduced opportunities in international markets. According to Porter and Kramer (2011), sustainable competitiveness should be seen as a strategy for creating shared value, that is, one that generates economic gains for the company while simultaneously promoting social and environmental benefits.

This concept applies directly to road logistics, where companies that invest in clean technologies, preventive maintenance, and route optimization not only reduce expenses but also win over customers and investors who prioritize responsible practices.

The transition to sustainable logistics, however, is not homogeneous across companies. Studies by Christopher (2016) demonstrate that large multinational companies are able to internalize sustainability practices more quickly due to the availability of capital and access to innovation. Small and medium-sized transport companies, on the other hand, face greater barriers, especially related to the high initial costs of technologies such as hybrid or electric vehicles. In this scenario, competitiveness also depends on the ability to form partnerships, collaborative networks, and logistics consortia that allow for cost sharing and scale generation. This collaborative strategy, as Chesbrough (2003) points out, is directly linked to the concept of open innovation and the possibility of accelerating transformations in highly complex sectors.

The regulatory dimension also exerts a strong influence on business competitiveness. Companies that anticipate environmental legislation and invest in sustainable practices before they become legally required gain a significant competitive advantage. The European example of the Euro VI Directive, which establishes strict limits for heavy-duty vehicle emissions, shows how prepared companies gain greater market share by meeting environmental requirements ahead of their competitors (European Commission, 2019). In Brazil, legislation such as the Program for the Control of Air Pollution by Motor Vehicles (PROCONVE) serves as a benchmark, but still lacks greater rigor and enforcement. Therefore, companies that internalize international sustainability standards become more competitive not only in the domestic market but also in international trade.

Sustainable competitiveness is also related to companies' ability to demonstrate transparency and traceability in their operations. As Elkington (1997), a pioneer of the triple bottom line concept, notes, organizations that measure and disclose their environmental, social, and economic performance indicators build greater credibility with stakeholders.
In the transportation sector, this means monitoring carbon emissions, fuel consumption, and social impacts, transforming data into auditable reports that can be used as a negotiation tool with clients. Companies that demonstrate such practices tend to attract long-term contracts with large shippers and industries, reinforcing the link between sustainability and competitiveness.

Another aspect that reinforces business competitiveness is the end consumer's perception of sustainability. Research by Nielsen (2018) reveals that 73% of global consumers say they are willing to change their consumption habits to reduce environmental impacts, and 46% would be willing to pay more for products and services from sustainable companies. This behavior directly impacts logistics, as industrial and retail customers seek carriers that can guarantee a cleaner supply chain. Thus,

Companies that incorporate green logistics practices not only reduce internal costs, but also conquer markets that prioritize social and environmental responsibility.

The adoption of environmental certifications and international management standards also strengthens business competitiveness. Standards such as ISO 14001, which establishes environmental management systems, and ISO 50001, which focuses on energy efficiency, are increasingly valued instruments in the logistics sector. According to Jabbour and Jabbour (2016), certified companies have greater ease in accessing foreign markets and negotiating financing with banks that prioritize sustainable projects. In road transportation, certifications can represent a decisive competitive advantage, especially in public tenders and international contracts that require proof of responsible practices.

Business model innovation is another important dimension for competitiveness. Companies that successfully integrate sustainability into their value proposition develop differentiators that go beyond price or delivery speed. Examples like DHL, which invested in carbon-neutral transportation solutions and launched the GoGreen program, demonstrate that sustainability can become part of a company's corporate identity and attract global customers. As Hart (1997) notes, companies that integrate environmental issues into their core strategy not only protect themselves from risks but also create new growth opportunities. This alignment between innovation, sustainability, and competitiveness reinforces the importance of strategic vision in the logistics sector.

Finally, it is essential to emphasize that business competitiveness in road transportation should not be seen as a trade-off between costs and sustainability. According to Sachs (2015), environmental and social costs neglected in the present translate into future economic liabilities, whether through regulatory sanctions, loss of reputation, or exclusion from markets. Thus, companies that adopt sustainable practices not only reduce risks but also build lasting competitive advantages in an increasingly demanding global scenario. Competitiveness, in this sense, becomes inseparable from sustainability, establishing itself as an inevitable path for the future of road logistics.

6. Cost Management and Sustainable Operational Efficiency

Cost management in road transportation is one of the biggest challenges for companies in the sector, especially given the continued rise in fuel prices. According to data from the National Transportation Confederation (CNT, 2021), diesel accounts for an average of 40% of the total costs of a transportation operation, highlighting the need for operational efficiency strategies. In this scenario, sustainable practices such as route optimization, the use of alternative fuels, and preventive vehicle maintenance not only reduce environmental impacts but also directly contribute to cost reduction. Thus,

sustainability and efficiency cease to be opposing concepts and become complementary dimensions of business management.

One of the key aspects of sustainable cost management is the adoption of digital technologies for monitoring and analyzing data. Telemetry tools, for example, allow real-time monitoring of vehicle performance, identifying fuel waste and inefficient driving patterns. Studies by Waller and Fawcett (2013) show that companies that adopt big data analytics systems can reduce their operating costs by up to 20%, in addition to significantly reducing carbon emissions. Predictive analysis of mechanical failures also contributes to efficiency, preventing unexpected breakdowns and extending vehicle lifespans. This set of technologies transforms cost management into a continuous, evidence-based process.

Preventive maintenance is another decisive factor for sustainable operational efficiency. According to Christopher (2016), poorly maintained vehicles consume up to 30% more fuel and emit higher levels of pollutants. Adopting planned maintenance programs not only ensures greater fleet reliability but also reduces emergency repair costs and avoids unscheduled downtime. Furthermore, driver training in economical driving helps optimize fuel consumption, reducing operating costs by up to 15%, according to data from the United States Environmental Protection Agency (EPA, 2019). These practices demonstrate how cost management can be directly aligned with environmental sustainability.

Another relevant aspect is the diversification of the energy matrix in road transportation. Although diesel still predominates, alternatives such as compressed natural gas (NGV), biodiesel, and partial fleet electrification are already showing significant results in reducing costs and environmental impacts. Studies by Goldemberg (2010) show that partially replacing diesel with biofuels can reduce long-term operating costs by up to 10%, especially in countries like Brazil, which have agricultural infrastructure conducive to renewable energy production. However, the economic viability of these alternatives depends on consistent public policies and tax incentives that encourage their widespread adoption.

Sustainable cost management also involves the integration of collaborative logistics. Sharing fleets, consolidating loads, and using digital intermediation platforms reduce costs and emissions by increasing vehicle occupancy efficiency. According to Cruijssen et al. (2007), collaborative practices can reduce companies' logistics costs by up to 25% while significantly reducing carbon emissions. This trend reflects a cultural transformation in the transportation sector, in which pure competition gives way to strategic cooperation as a tool for achieving operational efficiency.

Measuring environmental and economic performance indicators is also essential for sustainable cost management. According to Kaplan and Norton (1996), balanced

Scorecards adapted for logistics allow you to integrate financial, environmental, and social goals into a single dashboard. In road transportation, this means tracking metrics such as average fuel consumption, COÿ emissions per kilometer traveled, and costs per ton transported. By aligning sustainability indicators with cost reduction objectives, companies can create more transparent and strategic processes, capable of generating a competitive advantage in increasingly demanding markets.

Another important point is the role of innovation in cost management. Companies that invest in research and development to create lighter, more aerodynamic vehicles with alternative propulsion systems can reduce both operating costs and environmental impacts. According to Rodrigue (2020), each 10% reduction in truck weight can generate fuel consumption savings of up to 6%, demonstrating the importance of rethinking the design of transportation vehicles. The adoption of low-rolling resistance tires and energy recovery technologies, such as hybrid systems, also reinforce the connection between efficiency and sustainability.

Finally, it is important to emphasize that sustainable cost management should not be seen simply as a set of operational practices, but as a strategic shift in business mindset. As Sachs (2015) observes, sustainability represents a new logic of economic development, in which environmental and social costs are internalized as part of the competitive strategy. In this sense, transportation companies that adopt sustainable cost management practices not only survive in a challenging market but also position themselves as leaders in innovation and responsibility, aligning their results with the development of a more just and balanced economy.

7. Technological Innovation and the Future of Sustainable Logistics

Technological innovation plays a decisive role in the future of sustainable logistics applied to road transportation. In recent years, advances such as fleet electrification, vehicle connectivity, and the use of artificial intelligence (AI) for logistics management have established themselves as key tools for reconciling economic efficiency and environmental responsibility. As reported by Rodrigue, Comtois, and Slack (2020), technological evolution is transforming logistics into an increasingly data-driven field with algorithm-based decision-making, enabling significant efficiency gains. In the specific case of road transportation, innovation is not limited to vehicles but encompasses the entire chain of planning, monitoring, and execution processes, making logistics more intelligent, sustainable, and competitive.

Fleet electrification is considered one of the most impactful transformations in the sector. Companies like Tesla, Volvo, and Scania have led the research and launch of large electric trucks, while pilot projects are beginning to emerge in Brazil in partnership with automakers and logistics operators. Studies by the International Energy Agency (IEA, 2022)

indicate that the electrification of road transport can reduce greenhouse gas emissions by up to 60% by 2050, provided it is accompanied by a clean energy matrix.
However, infrastructure challenges, such as the lack of large-scale charging stations and high acquisition costs, still represent barriers to its spread in emerging markets. This scenario reinforces the need for consistent public policies and government incentives to make the technological transition viable.

Another area of innovation is the digitalization of logistics processes, with a focus on the use of big data, blockchain, and artificial intelligence. Blockchain systems applied to logistics allow for the secure and transparent tracking and recording of all transportation stages, ensuring reliability in the supply chain. Artificial intelligence can be used to forecast demand, adjust routes in real time, and optimize energy consumption, as Waller and Fawcett (2013) argue. Furthermore, the use of machine learning algorithms has the potential to predict mechanical failures in advance, reducing maintenance costs and minimizing environmental impacts associated with unexpected transportation interruptions. Thus, technological innovation contributes to building a more resilient and sustainable logistics model.

The integration of innovation and sustainability is also evident in the development of new materials and vehicle designs. Lighter trucks, with structures made of advanced metal alloys or carbon fiber composites, allow for greater energy efficiency, as pointed out by Rodrigue (2020) and Hart (1997). Furthermore, vehicle aerodynamics have been improved through mechanical engineering studies and computer simulations, resulting in a significant reduction in fuel consumption. This pursuit of design efficiency not only reduces operating costs but also reinforces the road transportation sector's environmental commitments, aligning engineering and sustainability.

In terms of operational sustainability, biofuels remain a viable and strategic alternative for developing countries. Brazil, for example, stands out as a world leader in ethanol and biodiesel production, which gives the country competitive advantages in terms of diversifying its energy matrix. Studies by Goldemberg (2010) confirm that the use of biofuels can reduce greenhouse gas emissions by up to 80% compared to fossil diesel, provided it is accompanied by sustainable agricultural practices. This perspective reinforces that technological innovation should not be limited to high-cost global solutions, but also incorporate local realities that can increase competitiveness and reduce environmental impacts.

Another area of technological innovation in road logistics is the development of autonomous transportation systems. Companies like Google (Waymo) and Daimler have invested in autonomous trucks capable of operating long distances with lower energy consumption and greater safety. According to a report by McKinsey & Company (2021), the use of autonomous trucks can reduce transportation costs by up to 45%, while also reducing accidents and

carbon emissions. Although still far from the Brazilian reality, the global trend points to a radical transformation of the sector, in which automation will be a central element of competitiveness and sustainability.

Innovation also connects with circular economy concepts applied to logistics. This includes everything from the use of recycled tires to the adoption of vehicle component reuse practices, reducing the extraction of natural resources. According to the Ellen MacArthur Foundation (2019) report, the circular economy in the transportation sector could generate economic benefits exceeding US$4.5 trillion by 2030, reinforcing the potential of sustainability as a driver of competitiveness. In road logistics, this means creating a longer life cycle for equipment and components, reducing costs and environmental impacts.

Ultimately, the future of sustainable logistics will depend on an alignment between technological innovation, public policies, and business behavior. According to Sachs (2015), sustainability must be viewed as a new development paradigm, in which innovation is a fundamental driver for generating competitiveness and ensuring environmental preservation.
Therefore, companies that can internalize innovation as part of their organizational identity will be better positioned to lead the transition toward more sustainable and efficient road logistics. The future of the sector, in this sense, will be marked not only by cost reduction but also by the construction of new business models that integrate the economy, society, and the environment into a virtuous cycle.

Conclusion

The analysis of sustainable logistics applied to road transportation allows us to understand that competitiveness and social and environmental responsibility are not antagonistic dimensions, but rather complementary ones. The study of the various aspects addressed here demonstrates that companies that incorporate sustainability practices into their logistics processes not only reduce operating costs but also gain competitive advantages in increasingly demanding markets. As Porter and Kramer (2011) argue, creating shared value is today one of the main ways to integrate business and social objectives, and in road transportation, this logic is embodied in investments in innovation, efficiency, and environmental responsibility.

The role of public policies is also essential in enabling the sector's transformation. Programs to encourage fleet electrification, stricter environmental regulations, and support for research into alternative fuels are essential for aligning Brazilian companies with international sustainability standards. In this sense, it is observed that countries that have adopted advanced environmental legislation, such as those in the European Union,

are at the forefront of the transition to green logistics, creating barriers to entry for competitors that still operate with traditional models (European Commission, 2019).

Technological innovation is one of the central pillars for the future of sustainable road transportation. Digital monitoring tools, electric vehicles, renewable fuels, and logistics automation represent solutions that, in addition to mitigating environmental impacts, increase operational efficiency and reduce costs. However, as authors such as Rodrigue (2020) and Sachs (2015) warn, innovation must be accompanied by structural changes in business mindsets so that sustainability ceases to be seen as a cost and becomes a strategy for growth and industry leadership.

The study also highlights that sustainability in road transportation is not only an environmental issue, but also a social and economic one. Children, communities, and workers are directly impacted by companies' logistics choices, making social and environmental responsibility an ethical commitment. The adoption of collaborative practices, such as load consolidation and fleet sharing, reinforces the need to rethink the sector's competitive logic, replacing it with more inclusive and cooperative models (Cruijssen et al., 2007).

Therefore, it can be concluded that sustainable logistics applied to road transportation represents an inevitable path for companies that wish to remain competitive in the long term. More than just reducing immediate costs, sustainability should be understood as a strategic investment that ensures resilience, reputation, and access to higher-value-added markets. Leadership in the sector, in this sense, will be achieved by organizations capable of balancing efficiency, innovation, and environmental responsibility, consolidating their position as protagonists of a fairer and more sustainable logistics future.

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