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## Article

# A PESTLE analysis of the trucking industry: key insights and implications

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# A PESTLE analysis of the trucking industry: key insights and implications

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## ABSTRACT

Trucks are essential for transporting goods in today's economy, and heavy truck technology is advancing rapidly. New advancements include electric trucks, internet of things applications, and advanced safety features. However, there are challenges with adopting emerging technologies, such as autonomous trucks and artificial intelligence, as well as issues like driver shortage, safety, fuel costs, and contamination. Despite advancements, comprehensive research is still needed to address all factors impacting the industry. In this study, we conducted a systematic analysis using the PRISMA methodology to identify and analyze the factors impacting the trucking industry to better understand future driving forces. We searched the Web of Science and Scopus databases for January 2018 to July 2024 records. We analyzed 66 out of 108 selected records using the PESTLE methodology, which examines Political, Economic, Social, Technological, Legal, and Environmental factors. Our results show that 87% of the investigations focused on technological, social, and environmental factors, while 13% focused on other topics. Our findings show the significant impact of technology on the industry. Electric trucks introduce various implications, including fully autonomous trucks, the need for modern infrastructure, the displacement of drivers, and the demand for more advanced skills to operate increasingly high-tech trucks. The introduction of policies related to emission reduction, taxes, and subsidies for clean energy faces resistance from drivers, managers, and owners. Other key findings included the barriers to adopting alternative fuels, such as the need for charging stations and distribution networks and the need for implementing policies that support alternative energy sources.

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## 1. Introduction

TRUCKS are vital for transporting goods from companies to distributors, retailers, and customers. Trucks serve businesses of all sizes, both in urban and rural settings. They transport items from rail yards, ports, and airports to their final destinations. In 2022, the 'Transportation Statistics Annual Report' revealed that, in the U.S. alone, all trucking companies moved 73% of the cargo valued at 13.1 billion dollars (U.S. Department of Transportation, 2022).

Currently, the trucking industry faces several difficulties, such as driver shortages, vehicle accidents, and fuel price increases, which negatively impact the economies of these businesses. For example, transportation is one of the most significant contributors to greenhouse gas (GHG) emissions, accounting for 27% of total GHG emissions in the U.S., and medium and heavy vehicles constitute 26% of these emissions (Environmental Protection Agency, XXXX). A concerning problem is the 5,788 fatalities in crashes involving large trucks, as indicated by the 'Traffic Safety Facts Report' of 2021. This underscores the need

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for more contributions to improve traffic safety (National Highway Traffic Safety Administration & U.S. Department of Transportation, 2022).

As the trucking industry shifts toward sustainability, key manufacturers are leading advancements in electric, autonomous, and Artificial Intelligence (AI) technologies. Daimler Truck is focusing on electric vehicles to reduce emissions and environmental impact. They are developing the all-electric *eCascadia* as part of their sustainable transportation solutions. In collaboration with Torc Robotics, they aim to introduce SAE Level 4 autonomous trucks for hub-to-hub operations in the U.S. by 2027 (Buttler, XXXX). DSV and Volvo Trucks are collaborating to deploy 300 zero-emission electric trucks in Europe, contributing to DSV's goal of 2,000 electric trucks by 2030, making it one of Europe's largest fleets of heavy electric trucks (Lind, 2024).

Transportation companies are actively adopting emerging technologies. Uber is enhancing its Uber Freight platform with advanced technologies. The company is updating its Transportation Management System (TMS) to provide a next-generation, predictive user experience. This upgraded TMS will support various transportation modes, allow for the rapid addition of new features, and integrate with other systems like ERP (Freight, 2024).

On the academic side, the research in (Engström et al., 2019) reviewed recent advancements in automated trucking, identified key deployment factors, and highlighted the challenge of diverse transport operations and the limited comparisons of truck development. In (Zinn et al., 2018), the lack of women in logistics and supply chain management, especially in senior roles, was highlighted. The study explored the reasons for this gap. The research presented in (Siahaan et al., 2021) focused on prioritizing and identifying existing studies on the truck-sharing economy concept while also addressing gaps in the broader sharing economy literature. Studies such as (Nævestad & Hesjevoll, 2023) have investigated economic driving and management practices at the organizational level to help companies optimize their operations. In (Mahajan et al., 2024), a systematic review using the PRISMA method analyzed stakeholder perspectives—drivers, policymakers, and fleet owners—on automated truck platooning, drawing from previous studies and discussions.

Despite significant advancements in the trucking industry, a considerable gap persists in holistic research addressing all the factors impacting the industry. This gap highlights the need for studies that analyze current and future sector challenges. Applying the PESTLE model to each factor offers a clear perspective on current needs and principles, helping to anticipate and plan for changes in the operating environment. This approach helps identify opportunities and threats early, enabling informed decision-making and proactive industry adaptation.

Therefore, our study aims to review recent publications and analyze present and future challenges. By doing so, we aim to provide a well-rounded understanding and address critical research questions, offering valuable insights to guide future developments and strategic decisions in the trucking sector. Our study focused solely on the transportation of heavy vehicles via roads. Exploring other cargo transportation methods, such as rail, maritime, and air transportation, is outside the scope of this investigation.

This paper is organized into six sections. The first section highlights the significance of the trucking industry, followed by a comprehensive literature review. It then explains the methodology used in the analysis, including basic statistics on the included papers, a bibliometric analysis of the identified keywords, and an overview of the PESTLE model. The fourth section presents the results and discusses the findings and implications. Finally, conclusions are drawn regarding the trucking industry's most crucial aspects and challenges, along with recommendations for future work.

Furthermore, the study analyzes the trucking industry's technological, social, environmental, economic, and political-legal factors. Finally, our study seeks to identify the main challenges and how they are addressed in the trucking industry.

## 2. Literature review

A systematic literature analysis was conducted using the Web of Science (WOS) and Scopus databases, which involved a search equation containing the following keywords: 'trucking', 'transportation', 'future', or 'scenarios'. Only articles from January 2018 to July 2024 were included in the analysis, following the principles of the PESTLE methodology to identify the primary factors impacting the trucking industry.

PESTLE refers to political, economic, social, technological, legal, and environmental factors (Casañ et al., 2021). The PESTLE methodology helps to identify the main perspectives that impact strategic plans and decision-making processes.

Articles that were not relevant to road transport with trucks were excluded. The review was organized into technological, social, environmental, economic, political, and legal themes according to the number of articles in each factor.

## 2.1. Technological factor

The trucking industry has experienced rapid technological advancement each day. The following paragraphs present the main technological topics identified in the literature review.

### 2.1.1. Autonomous trucks impacts

The shift from traditional trucks to self-driving vehicles presents various challenges and opportunities. This study (Keya et al., 2018) investigates the impact of Autonomous Trucks (ATs) on transportation and explores decision-making frameworks and policy options, including automation and regulated truck traffic. The most effective model discovered was the utility-regret hybrid mixed model. This model offers transportation planners and urban policymakers valuable insights to enhance the trucking industry.

Studies (Bray & Cebon, 2022) have examined how ATs can reduce fuel consumption and carbon emissions by reducing peak speeds. By lowering the speed from 90 km/h to 80 km/h or 70 km/h with a load capacity of 50%, emissions can be reduced by up to 14% and 26%, respectively. One of the benefits of ATs is that they do not have the exact requirements of human drivers, such as rest requirements. Additionally, it was discovered that reducing truck speed can lead to substantial savings.

Recent studies have examined the use of ATs over the next decade. One such study, conducted by (Simpson et al., 2022), utilized a method known as '*Integrated Choice and Latent Variable*' to forecast the adoption rate of ATs. The study interviewed 400 carriers over ten years to determine their preferences and perceptions of these technologies. The results show that medium and large companies were more receptive to adopting ATs. In addition, companies with an average travel time of over 500 miles were more likely to reject ATs. The adoption rate of level 3 ATs is predicted to quadruple or double the current 13% rate, depending on various peer effect coefficients.

The findings from the study (Konstantinou & Gkritza, 2023), which surveyed 200 trucking experts, reveal several concerns about the electrification intentions of managers and owners. Fleet managers are worried about the costs associated with charging, the availability and accessibility of charging infrastructure, and how these factors might affect the feasibility of operating electric trucks on a large scale. Additionally, annual mileage and the knowledge and awareness of innovative charging technologies play a significant role in their willingness to adopt electric vehicles.

An essential aspect of ATs is the perception of the drivers. Research (Orii et al., 2021) reveals that truck drivers' perception of automation is divided: some feared losing their jobs, while others appreciated partial automation and its supportive functions.

This paper (Hopkins & Schwanen, 2023) examines individual expectations about vehicle automation in the UK trucking industry based on 61 interviews with truck drivers, freight managers, industry representatives, and government officials. It finds some consensus on automation being easier on motorways and challenging to time accurately, but significant differences in views on truck platooning and driver roles. These expectations are heavily influenced by individuals' professional experience and broader changes in the freight sector.

One of the significant concerns regarding truck automation is battery life for long-distance travel. A numerical model was used to analyze whether an electric heavy-duty tractor-trailer could travel a 500 km route from Washington to Knoxville using lithium batteries (Depcik et al., 2019). The study considered various factors, such as terrain, weather, vehicle forces, auxiliary loads, and payload, to determine the ideal engine and battery capacity. The simulations revealed that all lithium-based advanced chemical batteries could meet the requirements using a standard payload of 16 tons after reducing the drag, rolling resistance, and weight. However, lithium-ion batteries are pushed beyond their limits, even with

significant power reductions, indicating that there are still technical and economic challenges in making them fully viable.

Concerns about battery life and truck charging are significant (Tong et al., 2021). evaluates the impact of transitioning to electric long-haul trucks on the electric grid and the environment. The study finds that switching from diesel to electric trucks would reduce direct energy consumption by 0.9 quadrillion BTU. However, the life cycle of energy use could increase depending on the electricity source. Charging electric trucks could consume 5% of the annual U.S. electricity supply, with peak charging loads potentially aligning with daytime solar power. Strategic planning could integrate truck charging with renewable energy to enhance grid efficiency and environmental benefits.

This study (Romanova et al., 2022) examines 2035 Russia's transportation strategy, which aims to enhance logistics services, establish a unified transport system, and fulfill economic requirements. This study emphasizes the advantages of using uncrewed vehicles, developing information technology infrastructure, and utilizing big data analytics. Additionally, it suggests prioritizing cargo transportation and catering to different age groups to promote e-commerce industry growth.

In a study conducted by Brown (2019), the benefits and drawbacks of ATs and their level of automation were analyzed. The study found that high-performance computers, field-programmable gate arrays, sensors, and robotic operating systems are crucial for real-time data processing.

The impact of different levels of AT automation was measured in (Pudasaini & Shahandashti, 2020). Technology was classified into five levels, from Level 1, where assistance was provided, to Level 5, where complete autonomy was achieved. The study included 31 participants from Fort Worth, Dallas, who were surveyed. Their findings revealed that drivers perceived benefits in terms of reduced accidents and increased productivity. ATs are also anticipated to enhance productivity, safety, and responsibility while minimizing accidents.

This analysis (Huang & Kockelman, 2020) predicts changes in U.S. highway and rail trade patterns due to the availability of self-driving vehicles. The simulation investigates journey time and cost scenarios. The model shows that automation's reduction in trucking costs increases truck flow values by 11% and decreases rail flow values by 4.8%. Longer-distance freight operations continue to be dominated by human-driven trucks, whereas self-driving trucks dominate distances of less than 500 miles. The projections will help prepare for the enhanced automation of transportation systems.

Electric trucks could boost road capacity. Study (Ramirez Ibarra & Saphores, 2023) uses microsimulations to examine speed changes and the shift to electric and connected trucks. It finds that 1,000 hp electric/hydrogen trucks (eTs) could replace the need for extra freeway lanes in busy freight corridors. While conventional trucks with cooperative adaptive cruise control offer minimal speed improvement, replacing them with eTs and upgrading I-710 ramps should handle the expected 2035 drayage demand without adding a new lane. The study suggests focusing funds on eTs and infrastructure improvements rather than new lanes.

### **2.1.2. Platooning technology**

Platooning occurs when a group of vehicles travels in a coordinated form. This technology is expected to provide numerous benefits, such as improved fuel and traffic efficiency, increased safety, and enhanced driver comfort. The arrival of ATs has opened the door to this concept; however, what are the potential implications of platooning?

In Bergenhem et al. (2012), a parametric analysis was conducted to explore the safe movement of convoy trucks on highway bridges. This study considered several factors, such as beam spacing, stretch lengths, and the number of trucks. It was discovered that platoons can carry heavier loads and move faster on bridges with short spans and low traffic. However, more information is required to establish safe-load guidelines.

A systematic review using the PRISMA technique in (Mahajan et al., 2024) analyzed the challenges of automated truck platooning (ATP). The review revealed that ATP's impact on employment is shaped by various scenarios, job creation potential, and the pace of automation. It also identified delays in ATP deployment due to gaps between research, stakeholder perspectives, and policy. To address these issues, the study suggests that infrastructure adaptation alone may not suffice and that push policies might be necessary to restrict the use of private or non-automated vehicles.

Researchers have conducted studies (Eitrheim et al., 2022) to examine the potential difficulties of platoons on rural freight routes in Norway. The study interviewed twenty-one experts who shared their insights into commercial potential, acceptability, organizational capabilities, and required infrastructure. These findings revealed that platoons could enhance volume handling, promote intermodality, and enhance safety. However, platoons require specific alignments, sight distances, climbing lanes, traffic separation, and digital communication systems, which pose significant obstacles to the adoption of the technology.

A study (Earnhardt et al., 2022) presented a fuel-efficient method for switching between coordinated platooning controllers and individual velocity trajectory optimization (VTO) controllers using model predictive control calculations. This study compared the results with a VTO without platoons and a reference controller. The research was conducted on two real-world trucking routes using the Simulink model provided by Volvo and two traffic scenarios. This strategy can reunite the platoon without consuming a large amount of gas.

The impact on roads was analyzed in (Okte & Al-Qadi, 2022); this study predicted the pavement's performance based on vehicle positioning. Researchers found that when traffic is distributed, there is a lower chance of pavement failure than channelized traffic. This means that the formation of ruts and cracks can be reduced by up to 20% and 40%, respectively, using distributed traffic. The calculation time for this method is 0.15 seconds. Platooning has several benefits, including reduced environmental carbon emissions.

One study (Bibeka et al., 2021) assessed the environmental impact of truck platooning; it used VISSIM to simulate platoons and calculate emissions based on trajectory data. Factors such as the market penetration rate, communication quality, and lane policies were considered. The results indicated that a gap of less than 0.2 seconds resulted in better emission benefits. Additionally, a slight change in the average speed of the network could significantly impact emissions.

The work cited in (Earnhardt et al., 2022) aimed to promote the creation of platooning among vehicles. This involves following a specific road route or changing routes to join the platoon. Three economic exchange methods were used to determine the value: (i) the Shapley value with a known trajectory, (ii) the Shapley value adjusted for traffic uncertainty, and (iii) offers from individual operators. Vehicles were incentivized to participate in fuel-optimal driving situations that would increase fuel consumption using these methods.

### **2.1.3. The use of Artificial Intelligence**

The trucking industry has also benefited from advancements in AI. The study (Budak & Sarvari, 2021) used machine learning (ML) algorithms to predict customer profit margins. Two analyses and a hybrid model were conducted using three different ML algorithms (random forest, robust regression, and XGBoost). The lowest root mean squared error value of 0.0250 was achieved in the last scenario, making it the most effective ML strategy.

In their study (Hu et al., 2020), they analyzed current research on accident predictions. They compared two traditional models, logistic and Poisson regressions, with two machine learning models, neural networks, and XGBoost, to model accident risk. Two strategies were implemented for re-routing loads: (i) re-optimizing pre-booked loads with new requests and (ii) optimizing new requests only (Hassan et al., 2022). A Mixed Integer Program (MIP) was used to determine routing. It was discovered that the savings obtained from option 1 increased proportionally with demand variability. However, when most loads were new arrivals, the cost of Option 2 was higher than that of Option 1.

Study (Sun et al., 2024) compared five clustering algorithms and applied Shapley additive explanations to analyze data from over 7,000 American truck drivers. The research identified key factors influencing safety climate perceptions across different driver clusters. It highlighted the crucial role of supervisory care in differentiating between driver groups, emphasizing its significance for effective safety climate interventions.

In (Adi et al., 2020), deep reinforcement learning (DRL) is applied to optimize truck routing for container transport orders, considering factors like order origin, destination, time window, and due date. The proposed Deep Q-Network (DQN) is evaluated against simulated annealing and tabu search algorithms.

The DQN demonstrates significant improvements in performance and solution quality, offering feasible solutions with shorter computational times compared to the baseline algorithms.

#### **2.1.4. Connected vehicles**

Researchers have experimented to determine the impact of Traveler Information Messages (TIMs) from Connected Vehicles (CVs) on drivers' speed decisions, according to (Yang et al., 2020). The study found that CVs TIMs significantly influenced the behavior of drivers, particularly during winter. Drivers tend to reduce their average speed and exhibit less speed variability, which can potentially reduce traffic incidents.

#### **2.1.5. Smart technology**

One study (Kermanshah et al., 2020) analyzed the benefits of utilizing smart GPS technology and revealed that incorporating such devices can significantly reduce expenses and CO<sub>2</sub> emissions. Implementing a smart GPS on just 1% of the trucks in Tennessee can lead to an annual cost saving of \$67 Million and social benefits of up to \$79 million. This technology can also reduce labor costs while simultaneously targeting CO<sub>2</sub> and SC-CO<sub>2</sub>.

#### **2.1.6. Digitalization**

Parihar (Parihar & Dasari, 2022) examined the challenges related to digital transformation within the trucking industry using a digital program from India and a log-log regression model. The findings reveal that the government should promote the development of new trucks equipped with digital technology, incorporate it into their departments, and offer training to ensure successful implementation. Furthermore, there should be support for small operators to form cooperatives, increase their efficiency, and enable them to adopt digital transformation.

Big Data analytics (BDA) has advanced transportation significantly. According to (Gorman et al., 2023), in trucking, hierarchical clustering and bi-objective mixed-integer programming have improved truck scheduling and container pairing, cutting empty truck trips by up to 34%. Real-time vessel data and standardized formats, like DCSA's just-in-time arrival standards, enhance port planning, reduce congestion, and lower CO<sub>2</sub> emissions. Synchromodality enables flexible multimodal planning, and real-time data integration improves transport efficiency and adaptability. Additionally, BDA helps predict performance, booking trends, and capacity utilization.

#### **2.1.7. Truck-drone**

A solution for the truck-drone routing problem was proposed with a time-dependent road travel time in (Wang et al., 2022). The proposed algorithm significantly improves the punctuality of deliveries and reduces mileage. An increase in drone delivery was observed when roads were congested.

#### **2.1.8. Blockchain**

Blockchains are an emerging technology that has already reached transportation. The authors (Panda et al., 2023) examined the use of blockchain in the trucking Industry in India and its implementation challenges. Among the benefits found were immutability, improved security, and reduced fraud. With its use, the operations and management strategies can be improved.

### **2.2. Social factor**

The trucking industry is affected by many social factors, and it is important to examine the environmental aspects of this element. This section explores several topics, including safety, social acceptance, refueling infrastructure, employment retention, and health impact, to better understand the social dynamics and experiences within the trucking industry.

### 2.2.1. Safety

The prevention of accidents on the road was addressed in (Yang et al., 2021) by utilizing a simulator, Connected Vehicle (CV), and Pilot TIMs to reduce accidents. The average speed profiles under the CV scenarios were lower than those under the baseline scenario. In addition, the experiment showed that the mean time-to-collision under the baseline was almost 40% lower than that under the CV scenario.

Truck rest-break mandates are implemented to reduce crash frequency and severity (Park et al., 2024). evaluates the impact of revising truck rest-break regulations on highway safety by using a Multilevel Full-Bayes model to analyze changes before and after the revision. The study found that the Multilevel Bayesian Poisson-gamma model provided the best results, showing a reduction in crashes following the updated rest-break rules. These findings offer valuable insights for improving road safety regulations.

Data such as fatigue, driving distractions, weather, and traffic were used (Hu et al., 2020) to explain and predict truck accidents. In addition, there exists a gap between the conclusions of modern descriptive/predictive studies and the assumptions regularly made in the operations research model.

In a recent study (Duvvuri et al., 2022), several factors, including land use and demographics, were examined to identify potential risk variables associated with the severity of injuries sustained during truck accidents. This study revealed that improving the geographic layout and increasing visibility can reduce the probability of injury in a collision. Implementing Intelligent Transportation System technologies such as dynamic messaging can also lead to safer vehicle maneuvering. In addition, warning and prevention technologies can be utilized in high-risk areas to minimize the incidence of accidents.

A recent study (Rezapour et al., 2021) found that past violations could predict future accidents. The study included risk factors such as weather and driver ability and recommended focusing on improving areas with bad weather and road conditions to reduce crashes.

The correlation between the four types of safety-critical events (SCE), crashes, injuries, and fatalities was analyzed (Cai et al., 2021) using Bayesian negative binomial models. They found that a one-unit increase in SCE per 10,000 miles led to an 8.4% increase in collision rates and an 8.7% increase in injuries.

One study (Das et al., 2020) analyzed fatal crashes caused by heavy trucks using taxicab correspondence analysis and data from 2010 to 2015. The results indicated many accidents at urban crossings and a correlation between heavy truck crashes and two-way roads with exposed medians. Human error clusters emerged, including impaired drivers and drivers with a history of crashes in weather-related incidents. Night driving was also linked to more accidents.

This study (Yang et al., 2021) provides safe platooning strategies for trucks with varying weights on bridges. A Monte Carlo simulation was used to determine the safe headways between platooning trucks, considering factors such as girder spacing, span lengths, and truck counts. The platoon loads can increase to 260% on easy-span bridges and 290% on two-span bridges.

Truck drivers face potential hazards in their jobs. In this study (Reiman & Väyrynen, 2020), the authors researched occupational safety and transportation methods and identified the nine challenges that they faced. These include safe load transport, secure loads, and harsh weather conditions. Safe transportation is crucial to society, and improvements are necessary.

The authors in (Douglas et al., 2019) found that the safety climate affects driver attitudes and intentions to commit unsafe acts by analyzing different system levels. Drivers with a higher aversion to risk are less likely to engage in dangerous behaviors. Carrier managers should use this information to understand drivers' risk perceptions and to implement safety policies and procedures.

Other study (Li et al., 2024) utilized user personas to identify and analyze safety risk factors affecting truck drivers. It summarizes methods for constructing these personas, focusing specifically on truck drivers. The study categorizes management interventions based on driver statuses into four temporal phases: pre-post, pre-transit, in-transit, and on-post. By examining these phases, the research highlights that incorporating a safety culture is a novel safety management intervention. This approach can impact drivers' intrinsic behavioral mechanisms and enhance the effectiveness of safety interventions at the cognitive level.

This study (Douglas, 2021) analyzes the literature on motor-carrier safety in the U.S., categorizing it by different levels of the industry system. However, the effects of policies and programs on carrier behavior remain unclear. Research should investigate trends and problems in the motor carrier industry, such as regulatory changes, driver turnover, technology adoption, and pandemic response.

### 2.2.2. Traffic

This study (Younes et al., 2020) evaluated truck re-routing tactics in incident-induced congestion situations. The focus was on improving truck traffic operations and assessing the effects of diversion techniques on alternative routes. Researchers should explore the advantages of employing the en-route diversion tactics of connected and automated trucks. Applying appropriate criteria for diversion can result in shorter travel times and maintain an acceptable level of service on alternate routes.

This study (Sadek et al., 2020) proposes a dynamic forecasting model to estimate truck parking occupancy using Fourier analysis. The performance of the model was evaluated using RMSE. The models were defined based on data analysis: static regular, trend-switching, and hybrid. The trend-shifting model was the most accurate for this dataset.

According to (Miller & Vavitta Parambil, 2024), inadequate planning for truck freight, relative to passenger transport, is a significant issue among regional planning agencies (RPAs). A survey of 22 Virginia RPAs found limited adoption of practices like emergency truck parking and zoning for parking needs, with only 23% of respondents showing interest. A pilot project with one RPA emphasized the need for better off-site truck unloading locations and resulted in a proposal to include truck parking in the county's comprehensive plan. These findings suggest that aligning truck freight planning with regional interests can enhance effectiveness and collaboration.

In 2020, the world experienced a significant pandemic with major impacts (Koliou et al., 2024). analyzed daily vehicle counts classified by the Federal Highway Administration in New York and Florida. The findings reveal that while overall traffic decreased drastically due to pandemic-related measures, freight transportation remained stable because of its crucial role in the supply chain. Analyzing truck traffic and freight movements is essential to ensure service continuity and prevent shortages in future crises.

### 2.2.3. Social acceptance factor

Adopting modern technology is always challenging; a survey of 400 US carriers (Simpson et al., 2022) found that medium and large companies are more likely to accept level 3 ATs than smaller ones. Companies with an average travel time of over 500 miles are less likely to adopt them. Those with a bachelor's degree are optimistic about ATs, whereas companies with employees aged 46-55 have low hopes. The peer effect results suggest that future adoption rates could double or quadruple from the current 13%.

On the other hand, the driver's perception was presented in (Orii et al., 2021). This study analyzed social media posts from the r/Trucker community on Reddit using Python Reddit API Wrapper. The findings showed that members were concerned about job loss and fairness. Some drivers expect partially automated vehicles with assistive functions; however, advanced automation may bring further concerns. The media's portrayal of automation does not align with reality, leading to disparities between perceptions and outcomes. We identified seven topics discussed by the community: jobs, feasibility, timelines, personal experiences, positive perspectives, Q&A, and expectations.

This study (Cantillo et al., 2022) analyzed the factors influencing Colombian companies' purchase of trucks running on alternative fuels. The survey found that the purchase and operating costs were the most significant factors. Emission levels are a minor factor in the decision-making process. This study emphasizes the importance of designing and implementing policies to promote cleaner alternatives to conventional fuels.

### 2.2.4. Refueling infrastructure for alternative energy

When switching trucks from diesel to hydrogen, a nationwide network of hydrogen refueling infrastructure is essential. Studies have (Yaïci & Longo, 2022) explored the feasibility of such a network and presented two algorithms for predicting fueling circumstances and economic analysis of various test scenarios.

Yaïci and Longo (Yaïci & Longo, 2022) researched a network of compressed Renewable Natural Gas (RNG) refueling stations to switch diesel trucks to RNG. The findings indicate that capital costs and interest rate changes do not affect RNG's selling price. However, yearly revenue or cost changes result in corresponding increases or decreases in the final selling price of RNG. It predicts fuel needs using traffic and infrastructure data and analyzes selling price factors through economic testing.

### 2.2.5. Human resources

The shortage of drivers is a concern in transportation. Kuiate and Noland (Kuiate & Nolan, 2019) explored whether businesses used retirement plans to retain skilled employees and whether they led to increased profitability. Financial data from long-haul freight carriers were analyzed using linear regression and other tests. The results show that retirement plans are linked to better employee retention and business success. Companies with pension benefits are likely to have a stable workforce.

According to (Schuster et al., 2023), a study of 67 industry experts, automated vehicles (AVs) may alleviate some of the shortage but will not fully resolve it. The ongoing challenge includes attracting younger workers who are deterred by poor job conditions and low pay. The study indicates that to address this, it is essential to improve working conditions and wages while developing targeted training programs for both technicians and drivers. These programs will help prepare the workforce for a future where automation plays a key role, ensuring that workers are trained to thrive in an evolving industry.

Using Principal Component Analysis and Ward's hierarchical clustering with O\*NET data, the study (Wang et al., 2023) identified potential alternative occupations for truck drivers in the event of displacement by autonomous vehicles (AVs) and examined the geographic distribution of both truck driving jobs and these alternatives. The results suggest that there may be insufficient job alternatives if 35% or more truck drivers were displaced. Furthermore, the available alternative jobs offer lower wages compared to truck driving positions. States, particularly in Middle America, are projected to lose many driving jobs and often lack sufficient alternative job opportunities. This highlights the need for targeted labor policies to support truck drivers in transitioning to new roles.

### 2.2.6. Impact on health

The article (Liu et al., 2019) looked at, among other things, the mortality caused by particulate air pollution, specifically, the impact of truck carbon emissions. The authors proposed implementing a carbon tax to encourage switching to alternative fuels to diesel. The simulation showed a 22% decrease in the mortality rate, in addition to a policy that imposes the maintenance of the truck fleet, which would cause the most significant reduction in emissions and the greatest decrease in mortality of 36%.

In (Heaton et al., 2024), a 59-item survey of 25 female truck drivers revealed they were sleep-deprived and had poor sleep quality. About 28% showed signs of post-traumatic stress disorder, but only 8% sought mental health care. Despite 80% having health insurance, some avoided care due to job conflicts. The study recommends telehealth services and screening by Department of Transportation medical examiners for mental health support.

### 2.2.7. Travel time

Weigh stations can reduce truck travel time reliability. A study (Samandar et al., 2018) at a weight station on I-95 in North Carolina found that truck travel time reliability decreases when the weight is operational. Using VISSIM microsimulation software, researchers found that weigh-in-motion technology can increase travel time reliability and help trucking companies and enforcement agencies.

Study (Bouyahyious et al., 2023) addresses the robust selective full truckload multi-depot vehicle routing problem with time windows, utilizing a mixed-integer linear programming approach to balance profit maximization and minimize worst-case travel times. This routing problem involves optimizing truck routes from multiple depots to various destinations under uncertain travel times while considering time windows for deliveries. Tested on 96 instances with up to 50 orders and five trucks using CPLEX 12.6, the method efficiently solved smaller problems but struggled with larger instances. Although robust solutions are feasible, they are not always superior to non-robust solutions.

## 2.3. Environmental factor

The trucking industry is also a cause for concern regarding pollution. It is one of the primary pollutants identified by the U.S. Environmental Protection Agency (Environmental Protection Agency, XXXX). Efforts are being made to reduce environmental emissions and find alternative fuel sources to replace diesel fuel.

### 2.3.1. Emissions reduction

New cyber-physical technologies in the trucking industry can significantly benefit the economy, environment, and society. According to (Kermanshah et al., 2020), if 1% of Tennessee's trucks use smart GPS technologies, annual cost savings equal \$67M, resulting in 219,162 metric tons of CO<sub>2</sub> emissions savings annually.

The study (Sproul et al., 2018) used *Autonomie* software to create three high-fidelity class 8 truck models for this study: one with an internal combustion engine (ICE), one with in-motion wireless power transfer (WPT), —a technology for operating and recharging electric vehicles—, and one with a long-range battery. NREL simulated real-world driving and found that in-motion WPT can reduce emissions by 12% and 7% compared to ICE and long-range battery trucks, respectively.

Researchers (Bray & Cebon, 2022) have analyzed the benefits and trade-offs of highway speeds for ATs. Lower speeds can significantly reduce fuel consumption and carbon emissions; for instance, a half-laden tractor-trailer can reduce fuel consumption and emissions by 14-15% when reducing speed from 90km/h to 80km/h and 26-28% from 90km/h to 70km/h. Even heavier vehicles can achieve absolute savings, but proportionally lower reductions are expected for the rolling resistance and aerodynamic drag.

Researchers have (Bibeka et al., 2021) analyzed the environmental impacts of simulated truck platooning. Setting a platoon gap is key to maximizing emission benefits. Compared to the 0.6s gap, a smaller gap of 0.2s led to better advantages. Even a slight change in the speed of platooning can significantly influence the emission rates.

This study (Baral et al., 2021) compared the costs and emissions of butanol production downstream using three types of trucks: diesel, fuel cell hybrid electric vehicles (FCHEVs), and fully electric trucks. *Autonomie* software was used to model fuel economy, hydrogen consumption, and electricity consumption. The results showed that electric trucks were the most efficient, followed by FCHEVs, and conventional trucks. Heavy loads and poor road conditions decrease efficiency. Electric and FCHEVs trucks reduced GHG by 11-25%, respectively, compared to conventional trucks transporting biomass feedstock.

In (Jones et al., 2024), the USLHC8 drive cycle was used to evaluate different powertrains for their emission reduction potential. USLHC8 demonstrated significant advantages: it covered 599.43 miles with a maximum speed of 70.87mph and a total driving time of 10hours and 46minutes, near the legal maximum of 11 hours. This cycle effectively represents long-haul driving conditions, making it a valuable tool for assessing and optimizing powertrain performance to reduce emissions.

This study (Mishra et al., 2024) forecasts emissions growth in India's trucking sector to 2050 using an ARIMAX model. It finds that vehicle scrappage policies could reduce emissions by 1-11%, while fleet electrification could reduce emissions by 35% for heavy vehicles compared to business-as-usual scenarios by 2050.

### 2.3.2. Climate impact

This study (Cezarino et al., 2021) examined the impact of the transportation industry on air pollution in Brazil's major metropolitan region. Research shows that the haulage industry needs to consider the harmful effects of air pollution on its risk management. The results obtained helped to identify the following indices: Carbon Monoxide (CO) 27.2kg/year, Nitrogen Oxide (NO<sub>x</sub>) 13, 82kg/year, and Particulate Material 274.2g/km. This study suggests using S10 diesel technology to reduce emissions by up to 80%. The study recommends replacing older vehicles with newer and cleaner vehicles. This would increase fleet rates and decrease maintenance expenses for the businesses involved in transportation.

In (Liu et al., 2019), the authors studied the environmental and health impacts of U.S. freight transportation under different policy scenarios. A carbon tax was the most effective policy, reducing emissions by 24% and 26% for short- and long-lived pollutants, respectively. Compact urban development has only a negligible impact on emissions.

Implementing a maintenance requirement for truck fleets reduces air pollutant emissions and fatalities by 36%. Switching from trucks to railways and using low-carbon fuels can reduce emissions further.

### **2.3.3. Alternative fuels**

Many people are interested in alternative fuels to reduce emissions into the environment. The two alternative fuels analyzed were hydrogen gas (Yaïci & Longo, 2022) and natural renewable gas (Yaïci & Longo, 2022). Infrastructure networks were examined to determine the feasibility of recharging these fuels for heavy trucks.

### **2.3.4. Feasibility fuel**

Programs that improve efficiency, such as Super-Truck II in the United States, pose a significant challenge to freight railways. Currently, railways are the most cost-effective and environment-friendly option for transportation (Iden, 2019). Other works, such as (Nævestad & Hesjevoll, 2023), also focus on reducing emissions and improving fuel consumption. This study, through a systematic literature review, developed a straightforward, research-based model to enhance economic driving practices at the organizational level in trucking companies. The model aids organizations in systematically improving their energy management, reducing fuel consumption, managing costs effectively, and maintaining safety.

### **2.3.5. Considerations to change the type of fuel**

The authors (Cantillo et al., 2022) used an approach involving random utility theory-based discrete choice modeling to estimate how truck drivers and trucking companies in Colombia choose alternative-fuel vehicles. The study found that costs were the most significant factor in decision-making. Programs and regulations that encourage the adoption of cleaner technology, such as financial incentives and alternative fuel vehicle fleet renewal pilots, may help reduce the emissions caused by freight transport (Cantillo et al., 2022).

## **2.4. Economic factor**

Economic factors are crucial for determining a company's profitability or losses; they are critical in making or breaking a company's success. This section delves deeper into ongoing studies analyzing the economic impact on the Trucking Industry.

### **2.4.1. Economic prediction**

This study (Shackman et al., 2021) analyzed the impact of global marine stock prices on major transportation businesses in the U.S. and other markets using Granger causality, which reveals that maritime stocks can predict future movements in other stocks. The results show that a 10% increase or decrease in Mitsui's stock price causes JB Hunt's stock price to fluctuate by 22.2%. Moreover, most maritime stocks accurately predicted the three non-maritime transportation equities analyzed in this study. These findings suggest that investors may use these techniques to select the trucking and rail firms they wish to support, although only long-term fluctuations can be forecast.

This study aims to develop risk-mitigation methods for the trucking industry while considering financial constraints (Dadsena et al., 2019). A multi-objective optimization model was used to determine the feasibility, necessity, and risk reduction of each proposed method. The best solution was identified based on the constraints and expert opinions. The results showed that the highest ROI (27%) was achieved with a specific strategy set at a budget of INR seven lakhs. This study highlights the relationship between risk intensity and cost, aiding better budget allocation for risk management. These findings can guide road freight carriers in constructing effective risk-management initiatives.

### **2.4.2. Infrastructure impact**

In (Kim et al., 2022), a framework for benefit-cost analysis was developed to evaluate the economic benefits of improving highways in the Dallas-Fort Worth region. They gathered data on freight-related traffic, the unit values of freight economic benefits, and project-specific data. The new highway construction project on Loop 9 Corridor from U.S. 67 to I-35E had the highest net benefit and benefit/cost ratio, with the most significant impact on future truck vehicle miles of travel and freight economic advantages.

### 2.4.3. *Smart technology*

As we have seen previously, smart technology affects economic factors. In Bergenhem et al. (2012), the authors studied the use of smart GPS technology in the Tennessee trucking industry. If 3% of trucks implement it, social benefits can exceed \$77 million. Even with just 1% adoption, it could save up to \$67 million and generate social benefits of \$79 million annually.

### 2.4.4. *Savings costs*

Three class 8 truck models, ICE, in-motion WPT, and long-range battery, were created (Sproul et al., 2018) and tested on driving cycles in empty and loaded states. An economic study showed that in-motion WPT trucks cost 35% less than ICE and 21% less than long-range battery trucks. In-motion WPT has the most significant benefit of tiny batteries, which reduce upfront costs.

A study (Bray & Cebon, 2022) explored the cost and carbon emission savings from ATs driving at lower speeds than human-driven ATs. The findings showed that reducing the speed from 90 km/h to 70 km/h could reduce fuel consumption and emissions by 26% for a loaded (50% cargo mass capacity) tractor-trailer. ATs traveling at slower speeds can save fleet operators and shippers costs. Employing per-mile pricing instead of per-hour pricing for autonomous technology suppliers may be an effective indirect pricing method.

### 2.4.5. *Economic incentives*

This study (Earnhardt et al., 2022) examined the use of platooning and economic incentives to increase fuel-saving platoons. Two methods have been proposed: incentivizing vehicles to catch up on a highway or changing their route. Three exchange-value methods were proposed. Three scenarios are examined to demonstrate the effectiveness of these methods. Two platooning scenarios were conducted using optimal algorithms and three exchange methods. The results show that economic incentives could increase fuel-saving platoons.

### 2.4.6. *Factors that impact RNG price*

An economic study (Yaïci & Longo, 2022) analyzed how different factors affect the selling price of RNG. The results indicate that capital cost and interest rate do not affect price, but yearly revenue and expenses do. Compressed renewable natural gas (CRNG) pricing can vary from CAD 0.40/diesel liter equivalent (DLE) to CAD 1.0/DLE depending on the RNG price. Different RNG manufacturing processes have different prices, and for every \$1/GJ increase in RNG, the CRNG increases with CAD 0.029/DLE. The average price of CRNG was 16.5% less than that of diesel before the tax.

## 2.5. *Political and legal factors*

Policies and laws play a crucial role in the functioning of industries and market growth. They are constantly evolving to keep pace with technological changes, society, the environment, and the economy. This section provides an in-depth analysis of how these regulations adapted to the changing landscape and ensured the operation of the Trucking Industry.

This study (Keya et al., 2018) examined the impact of automated cars on the shipping industry. Using innovative models, it examines the effects of various policies, including a carbon tax, increased truck shipping times, and automated fleets. The best-performing model found that adopting automation is better for long-haul private trucks than short-haul rentals.

This study suggests that a carbon price and shipping time penalty can shift transportation to rail or water-based options. Designated truck routes, controlled access to urban areas, and selected parking and loading-unloading infrastructural facilities can significantly improve truck transportation.

The strategies used by ten Chinese cities to promote electric logistics vehicles (ELVs) were analyzed in (Qiao & Raufer, 2022). Provinces in the east and south are most suitable for ELVs deployment because of the high freight turnover and air pollution concerns. These provinces offer subsidies, special road access, and charging incentives to promote the adoption of ELVs. Guangdong has the most established charging infrastructure, while Hunan and Sichuan require more assistance from regional administrations. Cities

**Table 1.** Research questions, the gaps identified in the literature review, and methodology.

| Gap                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Research Question                                                                                     | Methodology     |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|-----------------|
| The trucking industry is progressing in connectivity, automation, and electrification. However, decision-making is complicated by competing concepts and vested interests. Emerging technologies, such as digital transformation, blockchain, and AI, could enhance operational efficiency in the trucking industry. However, some challenges need to be addressed, such as high operating costs, operational delays, and the need for economies of scale. The industry is at a crossroads and must take decisive action in areas such as globalization, technology integration, partnerships, workforce transformation, regulations, and laws to thrive in the future                                                                                                                                                                                                                                                                         | <b>RQ1.</b> What future challenges are presented in transforming the Trucking Industry technologies?  |                 |
| There is a lack of research on the personal and social challenges that truck drivers face, such as being away from home for extended periods, feeling disconnected from their families, and the inclusion of female workers. This includes the impact of these challenges on truck drivers' physical and mental health. In addition, there is a need for programs that promote the acceptance and training of new technologies                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | <b>RQ2.</b> Which social developments have been identified that impacted the Trucking Industry?       |                 |
| Countries like Canada, China, and the U.S. have implemented new technologies and initiatives to reduce environmental impacts. However, further research is needed to identify opportunities for environmental improvement, such as the complete implementation of alternative fuels, infrastructure for the transportation of these fuels, and political implications in industry                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | <b>RQ3.</b> What opportunities exist to cushion the Trucking Industry's environmental impact?         |                 |
| The trucking industry could benefit economically if certain factors are considered. First, the cost of adding a more sophisticated range of system features should be considered, such as delivery time windows, traffic conditions, and vehicle routing options in the ATs software. Second, risk mitigation techniques and the degree of acceptability, sustainability, and reliability issues should also be considered. Third, contingency planning should be conducted while considering the financial constraints. Moreover, the growing use of cyber-physical (CP) technologies, such as smart GPS technologies, in the trucking sector has led freight operators to consider investing in emerging technologies that their current fleet lacks and accordingly plan for future investments. Finally, the state and local governments can encourage the adoption of CP technologies in the trucking industry by offering special grants | <b>RQ4.</b> What opportunities exist in the Trucking Industry to foster the economy?                  | PESTLE Analysis |
| Various policies, such as operational subsidies and road access privileges, have been introduced in countries like China to promote using NEVs. These policies can be implemented to encourage the adoption of alternative fuels in other countries. Disseminating the benefits of clean technologies can generate public interest. State and local governments can offer grants to encourage the adoption of emerging technologies, alternative fuels, and training programs in the trucking industry                                                                                                                                                                                                                                                                                                                                                                                                                                         | <b>RQ5.</b> What are the potential future political and legal challenges the Trucking Industry faces? |                 |

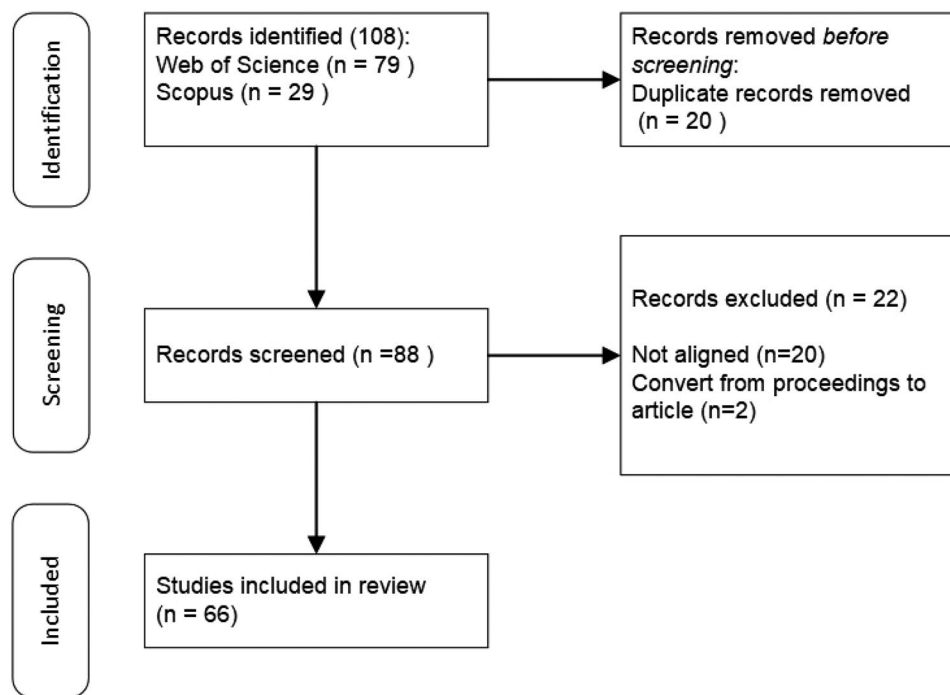
provide operating subsidies, road access privileges, and charging incentives to promote the adoption of ELVs. Shenzhen offers a comprehensive policy package for promoting ELVs.

Using econometric analysis, this study (Cantillo et al., 2022) uses Colombia as a case study to assess the characteristics that lead companies to buy trucks that run on alternative fuels. The survey found that the purchase and operating costs were the most significant factors. This study emphasizes the importance of designing and implementing policies to promote cleaner alternatives to conventional fuels.

The literature reviewed fails to provide a comprehensive view of the trucking industry and hence cannot offer guidelines and potential implications for the future of the trucking industry. To the best of our knowledge, our study is one of the first to identify future challenges in the trucking industry by integrating several political, economic, social, technological, legal, and environmental factors holistically. Table 1 presents a summary of the literature and explains the identified gaps along with associated research questions. In addition, we include the methodology used to answer our research questions. Because our study focuses on the trucking industry with a focus on heavy vehicles, other types of transportation are outside the scope of this research.

### 3. Methodology

This review was conducted following the PRISMA methodology. The PRISMA guidelines ensure the accurate and reliable reporting of systematic reviews and meta-analyses. This helps improve the quality of



**Figure 1.** Systematic review identification process of studies in the trucking industry.

reporting and supports evidence-based decision-making. PRISMA is applied in various fields, such as functional material characterization (Flores et al., 2022), the production of biodiesel using animal fats as feedstock (Andreo-Martínez et al., 2022), robotics sensors in primary and secondary education (Amo et al., 2021), and the implementation of emerging technologies (Valle-Cruz & Gil-Garcia, 2022).

Then, to present a comprehensive view of the analysis, we reviewed the Political, Economic, Social, Technological, Legal, and Environmental factors, also known as PESTLE analysis, associated with the research. Researchers in environmental studies, new product design, innovation, risk management, and multi-criteria decision-making have widely used the PESTLE methodology (Casañ et al., 2021; Saudi et al., 2021; Srdjevic et al., 2012). Hence, the PESTLE methodology provides a comprehensive view of current trends in the trucking industry.

The research process used in this study is illustrated in Figure 1. The process consisted of three phases, according to PRISMA: (1) identification, (2) screening, and (3) inclusion. First, we retrieve article publication data from WOS and Scopus. Our search query identified one hundred and eight records suitable for a review of trucking literature. We considered only articles related to future challenges in the Trucking Industry. Twenty publications were excluded because of duplication. Second, we screened eighty-eight publications that met the first criteria. Subsequently, 22 additional records were excluded because of a lack of alignment with the research scope. Finally, we include sixty-six articles analyzed following the PESTLE methodology principles.

### 3.1. Initial search

In November 2022, a search was conducted using the phrase 'Trucking Industry' in the Scopus, WOS, and Google Scholar databases. These databases' results were 767, 520, and 30,600, respectively. To narrow down the results, we refined the search using additional or synonym keywords such as 'trends' and 'carriers', plus limiting the results to those publications after 2017 (see Table 2). To obtain a better search, keywords were modified and replaced by 'truck', 'trends', and 'transportation'. Consequently, the search query suggested fewer articles for the two databases. The abstracts of these papers (see rows 4-6 on Table 2) were reviewed; however, they focused on specific current problems rather than technological, social, environmental, economic, or political-legal future challenges. Therefore, the keywords 'trends' and 'carriers' were removed and replaced with 'scenario' OR 'future', which generated 50 initial results in WOS and 19 in Scopus.

**Table 2.** Refined search log with the source.

| Num | Source* | Date       | Search Equation                                                            | # Results |
|-----|---------|------------|----------------------------------------------------------------------------|-----------|
| 1   | SC      | 11/07/2022 | "trucking industry" AND "trends" OR "carriers" >2017                       | 31        |
| 2   | WOS     | 11/07/2022 | "trucking industry" AND "trends" OR "carriers" >2017                       | 90,236    |
| 3   | SC      | 11/07/2022 | "trucking industry" + "trends" OR "carriers" >2017                         | 17,600    |
| 4   | SC      | 11/14/2022 | "truck" and "trends" AND "transportation" >2017                            | 526       |
| 5   | WOS     | 11/14/2022 | "truck" and "trends" AND "transportation" >2017                            | 53        |
| 6   | SC      | 11/14/2022 | "truck" + "trends" + "transportation" >2017                                | 24,300    |
| 7   | WOS     | 11/25/2022 | "trucking" AND "transportation" AND "scenarios" OR "future" >2017          | 50        |
| 8   | SC      | 11/25/2022 | "trucking industry" AND "transportation" AND "future" OR "scenarios" >2017 | 19        |
| 9   | WOS     | 08/05/2024 | "trucking" AND "transportation" AND "scenarios" OR "future" >2017          | 79        |
| 10  | SC      | 08/05/2024 | "trucking industry" AND "transportation" AND "future" OR "scenarios" >2017 | 29        |

\*SC=Scopus and WOS=Web of science.

In total, ten searches were conducted. Google Scholar results were discarded because of the wide range of documents. We determined that the queries in rows 7 and 8 were selected to obtain refined results. Hence, Scopus and WOS results were used in our study. The criteria chosen for the search were: ALL= ('trucking' AND 'transportation' AND ('scenarios' OR 'future')) >2017 from the WOS and ALL= ('trucking industry' AND 'transportation' AND 'scenarios' OR 'future')>2017 in Scopus databases. The search was updated four times, and the outcome in July 2024 for the WOS database yielded 79 results, while the Scopus database produced 29 (see the last two rows in Table 2).

### 3.2. Advanced screening and selection

The search equation produced eighty-eight results after applying the inclusion and exclusion criteria (Table 3). Twenty studies were excluded because they were duplicates in both the databases (WOS and Scopus). Two more articles were removed because they were initially published as proceedings before being republished as articles. Furthermore, 20 articles were discarded for not exclusively focusing on trucking transportation, including those that concentrated on maritime, air, or rail transportation. These articles analyzed raw materials, forest products, wood, biomass, and the costs associated with their operation (not exclusively trucking). Other studies have focused on water distribution in cities, among other topics. To focus on our investigation, we chose only to analyze the transportation of heavy cargo using class 8 trucks on roads. Class 8 trucks have a gross vehicle weight of 33,001 or more pounds.

We conducted an initial exploratory analysis of the 66 articles included in the review and conducted the annual distribution of different document types, as shown in Figure 2. The figure indicates that 2022 had the highest number of publications, with 16 scientific papers, whereas 2018 had the lowest, with only 3. Additionally, most publications were articles, with a total of 48, followed by 11 proceedings, 6 literature reviews, and just one book chapter.

In addition, we present a bibliographic map as an initial visual representation of the trucking domain (see Figure 3). The bibliographic map was developed using the open-source software VOSviewer (Arruda et al., 2022). The VOSviewer software enables the visualization of data categories (clusters) by calculating keyword frequency to identify gaps, overlaps, and trends in research (Hsieh et al., 2024). By mapping the relationships between different concepts, researchers can better understand the research landscape.

The map was created using bibliographic data from WOS from the papers that meet the inclusion criteria. Figure 3 presents a co-occurrence analysis of all the keywords from all the reviewed papers that meet the threshold of two minimum occurrences. The VOSviewer software identified that 109 of the 600 keywords meet the threshold, mapping eight clusters interconnecting 581 links. The bibliographic map structured the following core concepts: Trucking, Transportation, Infrastructure, Jobs, Vehicles, and Combustion. The core focus areas of the map represent the trucking industry trends, challenges, and opportunities identified from the literature review. It also presents future trends, technologies, and challenges impacting the trucking industry, such as platooning technologies, alternative energies, safety climate for drivers, etc. We used this information as an introduction to the PESTLE model.

We classified sixty-six papers using the PESTLE model as an information analysis technique, considering external factors that affect the trucking industry, such as political, economic, social, technological,

legal, and environmental factors (Institute of Leadership & Management, 2020). The literature review and discussion were organized based on the number of publications for each factor. The technological factor had the most significant impact, so it was presented first, followed by the social factor, and so on.

## 4. Results and discussion

The PESTLE analysis identified all relevant factors from the review documents. Therefore, using the PESTLE model as a guide, the results were categorized into five primary groups and subgroups accordingly. Our analysis of the available research identified several areas of innovation, including ATs, platooning, connected vehicles, AI applications, cyber-physical technologies, drones, digital transformation, and block-chain. Table 4 summarizes the findings and outlines the identified applications.

After grouping the technological, social, environmental, political, legal, and economic factors and trends, we created a framework that included the main factors identified in the analysis that influence the trucking industry ecosystem (see Figure 4).

Next, we discuss the advantages, barriers, disadvantages, and opportunities of the factors identified in the PESTLE analysis by answering each of the proposed research questions.

### 4.1. Technological

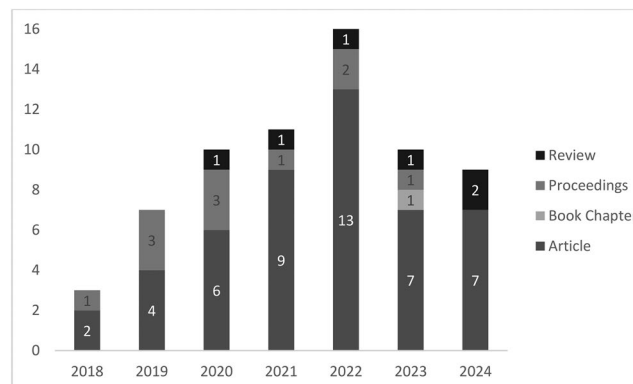
To answer RQ1. What future challenges are presented in transforming the Trucking Industry technologies? We can say that technology is progressing in giant steps daily. In the Trucking Industry, the transformation toward innovative technologies helps improve many aspects of the industry. The future challenges are discussed as follows.

#### 4.1.1. Autonomous trucks

The current study found that ATs help reduce carbon emissions and result in significant fuel savings. Another important finding is that ATs significantly contribute to reducing, predicting, and preventing accidents and increasing productivity because ATs have different break requirements than human drivers do. On the other hand, the research also found some barriers to adopting technology, as drivers fear losing their jobs. Another concern is the potential displacement of drivers to alternative employment and

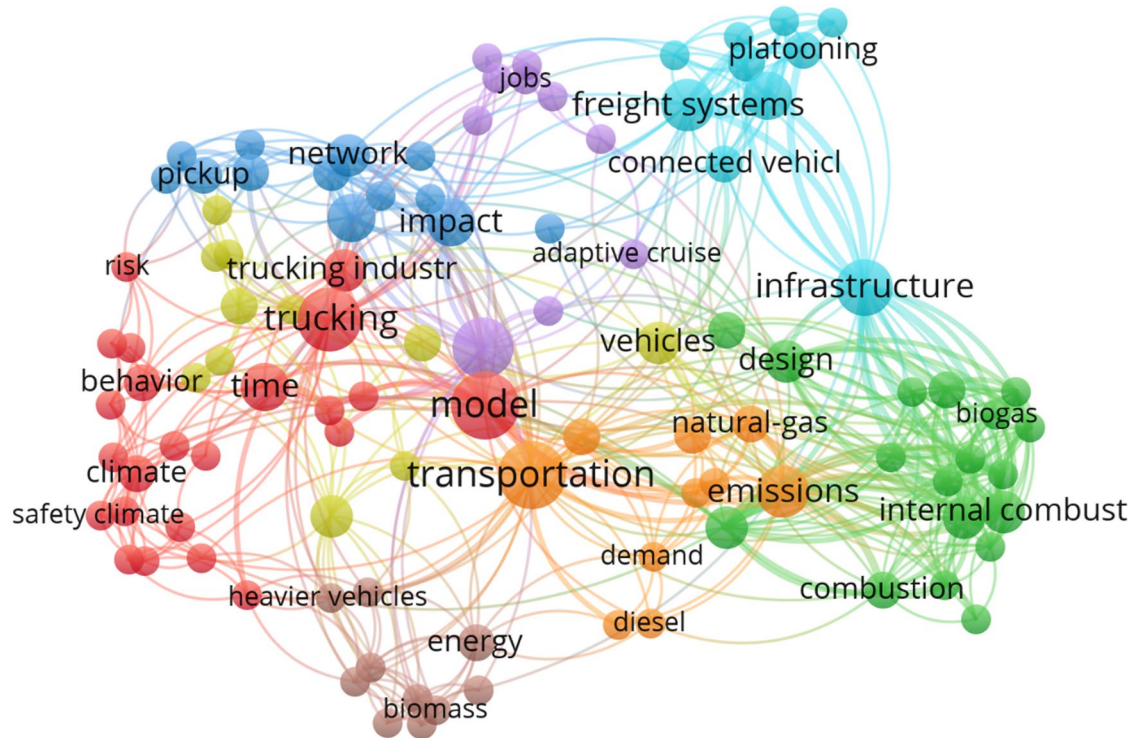
**Table 3.** Inclusion and exclusion criteria for publications.

| Inclusion criteria                                                                                                                                                                                                                                                                                                                                                                                                  | Exclusion criteria                                                                                                                                                                                                                                                                                                                                           |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>• Discuss the trucking industry.</li> <li>• Discuss technological opportunities and challenges for the trucking industry.</li> <li>• Highlight social challenges.</li> <li>• Cover the environmental impact of trucking.</li> <li>• Present economic factors that impact the trucking industry.</li> <li>• Address challenges related to policy or legal aspects.</li> </ul> | <ul style="list-style-type: none"> <li>• Discuss maritime transportation.</li> <li>• Concentrate on air transportation.</li> <li>• Address rail transportation.</li> <li>• Discuss applications within the trucking industry but with a focus on design and impact on concrete.</li> <li>• Tackle the impact of transportation costs on products.</li> </ul> |



**Figure 2.** Annual distribution of document type for included papers.

the wage reduction. It is crucial to develop policies to ensure that this transition is as smooth and supportive as possible. There is also resistance to ATs from companies, small ones, and those with long travel times (more than 500 miles). Among the principal disadvantages of ATs is battery life; although studies



**Figure 3.** Co-occurrence analysis of keywords of the Trucking Domain. *Source:* VOSviewer.

**Table 4.** Technological, social, environmental, economic, political, and legal factors and trends PESTLE.

| Category      | Factor         | Trend                                                    | References                                             |
|---------------|----------------|----------------------------------------------------------|--------------------------------------------------------|
| Technological | Impacts ATs    | ATs impact on the freight transportation system.         | (Keya et al., 2018)                                    |
|               |                | ATs and reduce speed strategy.                           | (Bray & Cebon, 2022)                                   |
|               |                | Adoption rate.                                           | (Simpson et al., 2022), (Konstantinou & Gkritza, 2023) |
|               |                | Trucker's perception.                                    | (Orii et al., 2021)                                    |
|               |                | Sociotechnical Expectations                              | (Hopkins & Schwanen, 2023)                             |
|               |                | Battery's life                                           | (Depcik et al., 2019)                                  |
|               |                | Truck charging                                           | (Tong et al., 2021)                                    |
|               |                | Strategies in trucking and incorporation of technologies | (Romanova et al., 2022)                                |
|               |                | Level of automation and drawbacks.                       | (Brown, 2019)                                          |
|               |                | Level of automation and advantages                       | (Pudasaini & Shahandashti, 2020)                       |
|               | Platooning     | Trade Flows                                              | (Huang & Kockelman, 2020)                              |
|               |                | Increase road capacity                                   | (Ramirez Ibarra & Saphores, 2023)                      |
|               |                | Bridges and infrastructure                               | (Yang et al., 2021)                                    |
|               |                | Main challenges                                          | (Eitrheim et al., 2022), (Mahajan et al., 2024)        |
|               |                | Controller rejoin                                        | (Earnhardt et al., 2022)                               |
|               | AI             | ATs and Human-Driven Trucks                              | (Okte & Al-Qadi, 2022)                                 |
|               |                | Emissions reduction                                      | (Bibeka et al., 2021)                                  |
|               |                | Predict fuel-optimal operation                           | (Earnhardt et al., 2022)                               |
|               |                | ML to predict the profit margin                          | (Budak & Sarvari, 2021)                                |
|               |                | Crash risk and accident prevention                       | (Hu et al., 2020), (Sun et al., 2024)                  |
|               | Connectivity   | Planning a route with full ATs                           | (Hassan et al., 2022)                                  |
|               |                | DRL in routing problem                                   | (Adi et al., 2020)                                     |
|               | Smart tech     | Reduce and prevent accidents                             | (Yang et al., 2020)                                    |
|               |                | Smart GPS                                                | (Kermanshah et al., 2020)                              |
|               | Digitalization | Digital transformation                                   | (Parihar & Dasari, 2022)                               |
|               |                | Big Data                                                 | (Gorman et al., 2023)                                  |
|               | Truck drone    | Truck-drone routing problem                              | (Wang et al., 2022)                                    |
|               | Blockchain     | Blockchain in TI                                         | (Dadsena et al., 2019)                                 |

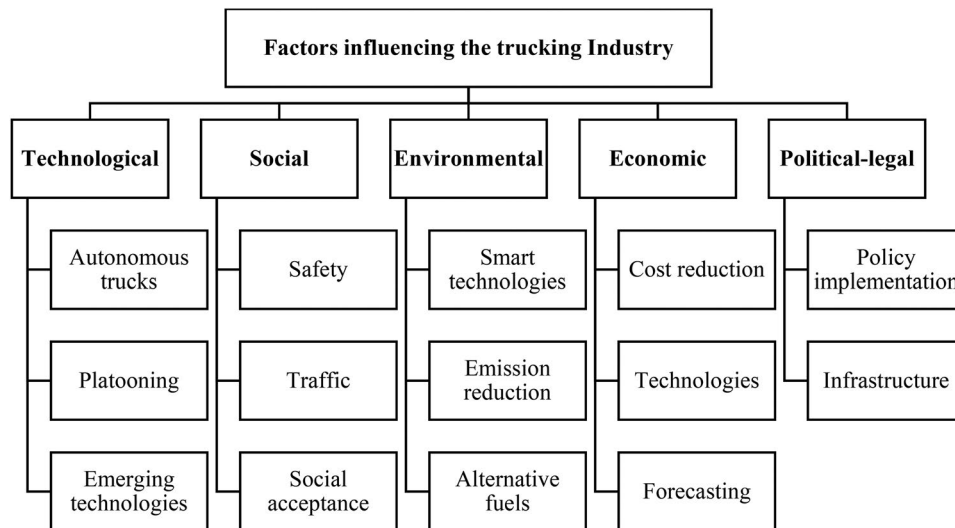
(Continued)

**Table 4.** Continued.

| Category      | Factor                          | Trend                                                                     | References                                              |
|---------------|---------------------------------|---------------------------------------------------------------------------|---------------------------------------------------------|
| Social        | Safety                          | Reduce and prevent accidents                                              | (Yang et al., 2020), (Park et al., 2024)                |
|               |                                 | Crash risk                                                                | (Hu et al., 2020)                                       |
|               |                                 | Identify the risk of crashing                                             | (Duvvuri et al., 2022)                                  |
|               |                                 | Predict future accidents                                                  | (Rezapour et al., 2021)                                 |
|               |                                 | Safety critical events                                                    | (Cai et al., 2021)                                      |
|               |                                 | Correlation patterns between various crash features                       | (Das et al., 2020)                                      |
|               |                                 | Safe headways between platooning                                          | (Yang et al., 2021)                                     |
|               |                                 | Safety for the drives                                                     | (Reiman & Väyrynen, 2020)                               |
|               |                                 | Drivers influence their safety                                            | (Douglas et al., 2019), (Li et al., 2024)               |
|               |                                 | Current literature state                                                  | (Douglas, 2021)                                         |
|               | Traffic                         | Congestion and traffic reduction                                          | (Younes et al., 2020)                                   |
|               |                                 | Parking occupancy and needs                                               | (Sadek et al., 2020), (Miller & Vavitta Parambil, 2024) |
|               | Social Acceptance               | Covid impact                                                              | (Koliou et al., 2024)                                   |
|               |                                 | Adoption for the companies                                                | (Simpson et al., 2022)                                  |
|               | Infrastructure                  | Driver's perception                                                       | (Orii et al., 2021)                                     |
|               |                                 | Factor to change clean energy                                             | (Cantillo et al., 2022)                                 |
|               | Human Resources                 | Hydrogen refueling infrastructure                                         | (Yaïci & Longo, 2022)                                   |
|               |                                 | RGN refueling infrastructure                                              | (Yaïci & Longo, 2022)                                   |
|               | Health impact                   | Retain employees and driver shortage                                      | (Kuiate & Nolan, 2019), (Schuster et al., 2023)         |
|               |                                 | Drivers displacement                                                      | (Wang et al., 2023)                                     |
| Environmental | Emission reduction              | Impact of reducing emissions on health                                    | (Liu et al., 2019)                                      |
|               |                                 | Women's Healthcare                                                        | (Heaton et al., 2024)                                   |
|               |                                 | Travel time                                                               | (Samandar et al., 2018), (Bouyahyious et al., 2023)     |
|               |                                 | Impact of Weigh stations, routing problem                                 | (Kermanshah et al., 2020)                               |
|               |                                 | CO <sub>2</sub> and SC-CO <sub>2</sub> emissions reduction with Smart GPS | (Sproul et al., 2018)                                   |
|               | Climate Impact                  | Comparison among ICE, WPT, and long-range battery                         | (Bray & Cebon, 2022)                                    |
|               |                                 | Varying speed in ATs                                                      | (Bibeka et al., 2021)                                   |
|               |                                 | Platoon gap setting                                                       | (Baral et al., 2021)                                    |
|               |                                 | Comparison among diesel, FCHEVs, and FE                                   | (Jones et al., 2024)                                    |
|               |                                 | Drive cycle in powertrains                                                | (Mishra et al., 2024)                                   |
|               | Alternative fuel                | Emissions forecast                                                        | (Liu et al., 2019)                                      |
|               |                                 | Emissions and climate impacts                                             | (Cezarino et al., 2021)                                 |
|               |                                 | Impacts on air pollution                                                  | (Mac Kinnon et al., 2021)                               |
|               | Fuel efficiency                 | Air quality and health effects                                            | (Yaïci & Longo, 2022)                                   |
|               |                                 | RGN network infrastructure                                                | (Yaïci & Longo, 2022)                                   |
|               | Change to alternative fuel      | Hydrogen stations                                                         | (Yaïci & Longo, 2022)                                   |
|               |                                 | Fuel efficiency                                                           | (Iden, 2019), (Nævestad & Hesjevoll, 2023)              |
| Economic      | Economic prediction             | Impact of ATs in freight transportation/ alternative fuels                | (Cantillo et al., 2022)                                 |
|               |                                 | Prediction of the transportation behavior                                 | (Shackman et al., 2021)                                 |
|               | Strategies                      | Risk mitigation                                                           | (Dadsena et al., 2019)                                  |
|               |                                 | Advantages in infrastructure projects                                     | (Kim et al., 2022)                                      |
|               | Infrastructure Smart technology | Economic impact                                                           | (Kermanshah et al., 2020)                               |
|               |                                 | Comparison ICE, WPT, LRB                                                  | (Sproul et al., 2018)                                   |
|               | Vehicle comparison              | Reduction cost                                                            | (Bray & Cebon, 2022)                                    |
|               |                                 | Incentives                                                                | (Earnhardt et al., 2022)                                |
|               | Savings                         | Factors that impact the price of RGN                                      | (Yaïci & Longo, 2022)                                   |
|               |                                 | Incentives                                                                | (Yaïci & Longo, 2022)                                   |
| Political     | Impact                          | Technological/ political/ legal                                           | (Keya et al., 2018)                                     |
|               |                                 | Policies in China                                                         | (Qiao & Rauffer, 2022)                                  |
|               |                                 | Policies in alternative fuels                                             | (Cantillo et al., 2022)                                 |

have been carried out on their resistance, there is still a long way to go to make them technically and economically viable.

ATs have many advantages; however, their barriers and disadvantages require significant attention. However, there is a great challenge for governments and the development of policies that regulate ATs. These challenges include, but are not limited to, the following: Electric truck charging could potentially consume 5% of the U.S. annual electricity supply, with peak loads aligning with daytime solar energy. New gaps in the labor market will emerge, requiring advanced technological skills to operate ATs and other emerging technologies. These results align with those of previous studies that indicate policies can safeguard workforce and industry interests while ensuring timely automation adoption (Mahajan et al., 2024). Key issues to address are the



**Figure 4.** PESTLE Framework of factors influencing the trucking industry.

traffic regulations for ATs, the impact on road infrastructure, how these technologies will affect or benefit drivers, and the types of subsidies needed to encourage companies to adopt ATs.

#### 4.1.2. Platooning

Platooning can improve volume management and safety as well as promote intermodality. The most significant benefits of this grouping of trucks are fuel savings, emission reduction, and improved safety. Safe platooning on bridges has been studied and found to be effective with low traffic and short spans.

Platoons also present obstacles to implementation because they require specific alignment, the distance between them, climbing lines, traffic separation, and digital communications. This finding is consistent with that of (Eitrheim et al., 2022), who identified that platooning would require re-evaluation of road parameters and infrastructure management because of the damage they can cause to roads; therefore, distributed traffic has been studied to minimize the impact on the pavement. Drivers' adoption is also an aspect to consider; thus, implementing economic incentives has been sought to address this. It is crucial to establish regulations that enhance the performance and integration of platooning.

#### 4.1.3. Emerging technologies

New and innovative technologies are advantageous to companies, clients, and users. By utilizing advanced predictive algorithms, companies can accurately forecast their profit margins, prevent accidents, and optimize their load-routing strategies. Furthermore, connected vehicles leverage TIMs to positively influence driver behavior, whereas smart GPS technology can promote economic and environmental sustainability. Finally, blockchain technology can potentially improve cybersecurity measures and significantly reduce instances of fraudulent activities.

Users and companies encounter barriers to the development of emerging technologies. These obstacles can be social resistance or financial constraints, which may hinder the adoption process. Nonetheless, it is crucial to understand that these issues are a part of the natural technological adoption cycle.

### 4.2. Social

To answer RQ2. Which social developments have been identified that impacted the Trucking Industry? We identified the following trends:

#### 4.2.1. Safety

The results of this study show that multifaceted measures can be implemented to strengthen the safety of the Trucking Industry. One of these measures includes using data analytics, such as fatigue and

driving distractions, to predict and prevent potential accidents. Additionally, experts identified risk variables and analyzed the impact of weather conditions on driver behavior. Another critical finding is the safety implications of platooning and its impact on roads and bridges. This concerted effort reflects a firm's commitment to mitigate potential hazards and safeguard the well-being of all.

#### **4.2.2. Traffic**

There is growing concern regarding the prevalent congestion experienced on roads and parking lots designated for trucks. Even with traffic re-routing measures, this issue persists because of the increasing number of people and vehicles on the roads. The adoption of ATs is expected to compound the problem further, necessitating a prompt and effective solution.

#### **4.2.3. Social acceptance**

The results suggest that medium and large companies adopt more ATs. Companies with older employees (ages 46-55) have lower AT technology adoption rates. This could be due to their experience with standard trucks and their hesitancy in switching to autonomous technology in its early stages. Meanwhile, truck automation with supportive features is more readily accepted than fully automated ATs because the latter may cause some drivers to be apprehensive. A pressing concern is the displacement of truck drivers by ATs. What will happen to these workers, and how will companies attract talent with the necessary skills to manage technology?

As companies prioritize environmental responsibility, the shift to clean energy is gaining traction. While alternative fuels offer clear ecological benefits over diesel, companies are also considering the additional costs of purchasing trucks that run on alternative fuels. Additionally, it is essential to have infrastructure networks to support the refueling of alternative fuels, such as hydrogen, natural gas, and electricity; this will ensure that companies can prioritize sustainability without compromising efficiency and practicality. Weigh stations are necessary but increase travel times for transporting goods. The Internet of Things technology can streamline monitoring and reduce wait times, but its implementation requires careful planning and execution.

This study identified several significant policies necessary for the transportation industry which would provide substantial social benefits. These policies include regulatory changes, driver turnover monitoring, technology adoption, and pandemic response. Additionally, the findings recommend implementing carbon tax and maintenance policies to encourage the use of alternative fuels.

### **4.3. Environmental**

To answer RQ3. What opportunities exist to cushion the Trucking Industry's environmental impact? We found that implementing smart technologies in trucks could decrease CO<sub>2</sub> emissions by approximately 219,000 metric tons annually. They also compared three different fuel sources for trucks and found that in-motion wireless power transfer technology can reduce emissions by up to 12% compared to traditional ICEs (Internal Combustion Engine).

Additionally, studies suggest that lowering the speeds to 70-80km/h could reduce carbon emissions from ATs by up to 28%. This effect is also observed during platooning. Alternatives to diesel, such as hydrogen, renewable natural gas, and electric power sources, are viable options for trucks. However, alternative fuels face obstacles, such as a lack of refueling infrastructure for long-distance trips of over 500 miles. In addition, cost is a significant factor in adopting these alternatives. Political strategies such as Super-Truck II (Brown, 2019) were found to promote the trucking industry as a strong competitor to rail transport, which is currently the most eco-friendly and cost-effective mode of transport. Despite this, policies that encourage a shift to alternative fuels still need to be developed.

### **4.4. Economic**

To answer RQ4. What opportunities exist in the Trucking Industry to foster the economy? We can say that the search for cost reduction is latent in any industry; innovations in the trucking industry include:

#### 4.4.1. Cost reduction

Strategies to allocate funds for risk management that reduce costs and the reduction of speeds in ATs could help reduce fuel consumption by up to 26%.

#### 4.4.2. Technologies

We also found that comparing in-motion WPT trucks against ICE, the cost of WPT could be up to 35% less than their ICE counterparts. Other findings are that the use of technology also boosts the economy. We found that implementing intelligent GPS technology in 3% of the U.S. trucking industry could yield over \$77 million in social benefits in Tennessee alone.

#### 4.4.3. Forecasting

Another important finding is that maritime stocks could be used to predict future movements in other transportation stocks. For example, a 10% increase or decrease in Mitsui's stock price causes JB Hunt's stock price to fluctuate by 22.2%.

### 4.5. Political-legal

Finally, to answer RQ5. What are the potential future political and legal challenges the Trucking Industry faces? During our study, we utilized various search equations to explore the selected databases; however, we found a limitation: we did not find research on the current policies being implemented in America. Nonetheless, we found:

1. Policy implementation

Studies that focused on policies in other countries, such as China, highlighted the specific policies implemented to boost the trucking industry. The findings in the policies are that cities from China offer operating subsidies, special road access, and charging incentives to promote the adoption of ELVs. They also provided a comprehensive insurance package for the promotion of ELVs.

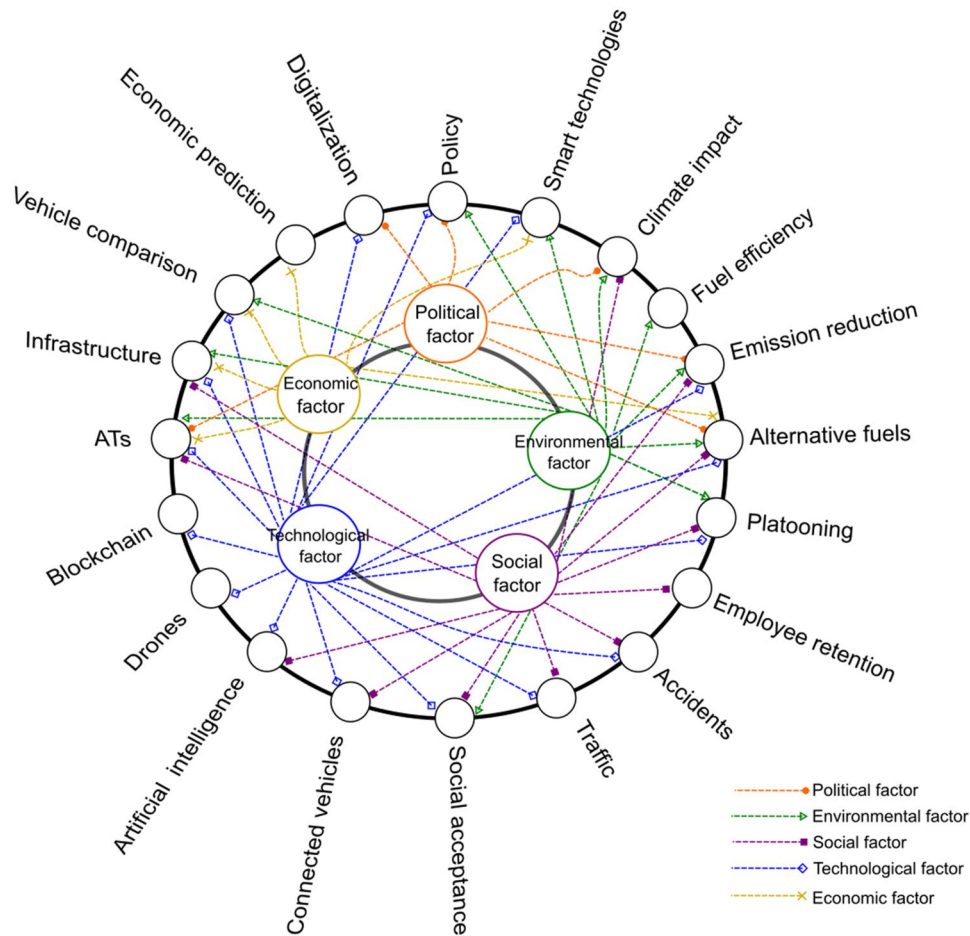
2. Infrastructure

Policies need to be implemented to transition to clean energy. Companies face challenges such as insufficient charging stations and energy distribution networks, making these policies essential for overcoming obstacles and ensuring a smooth adoption of new technologies while maintaining productivity.

The interactions between the trends and PESTLE factors are shown in [Figure 5](#). For instance, the 'Emission reduction' element affects the technological factor, as it benefits from using ATs to reduce emissions. Similarly, reducing air pollution is a crucial environmental factor positively impacted by 'Emission reduction'. This element can also benefit the economy in the long term by using alternative fuels. Another example is ATs, which impact all the factors. The technological aspect shows the advancements made in the trucking industry by reducing carbon emissions. In society, acceptance is necessary for adoption. From an economic perspective, it represents an essential factor to be adopted, and from a political perspective, ATs require regulations to be accepted.

## 5. Conclusions and future work

The present research aims to analyze present and future challenges in the trucking Industry. Applying the PESTLE model to each factor gives a clear vision of current needs and principles that will help to understand the possible impacts on road transport. This approach allows changes in the operating environment to be anticipated and planned, identifying opportunities and threats before they materialize. In this way, it facilitates informed strategic decision-making and promotes proactive adaptation to the changes that will shape the industry as it evolves. The following paragraphs present the conclusions about each factor.



**Figure 5.** PESTLE diagram of factors influencing the Trucking Industry.

The most prominent finding to emerge from this study is that the future of transportation is increasingly centered on technology, with autonomous and electric trucks, as well as AI, emerging as key areas of interest. Autonomous trucks offer a range of benefits and are poised to transform the industry by enhancing efficiency and safety. Electric trucks, for instance, have the potential to significantly cut emissions by replacing internal combustion engines with electric ones. Research into speed and coordination for autonomous trucks is promising, particularly in platooning and vehicle synchronization, which can reduce emissions, conserve energy, and improve traffic flow through enhanced connectivity with their environment.

AI algorithms are expected to become common tools for reducing human errors, and with the integration of the Internet of Things, this is becoming a reality. Drivers receive alerts about upcoming weather conditions in the next city, which helps them reduce speed and prevent accidents. Furthermore, integrating connectivity and AI will provide substantial safety improvements, including advanced systems for proximity detection and collision avoidance. The implementation of data collection devices enables real-time monitoring of vehicle status, facilitating proactive maintenance scheduling and reducing roadside repair costs. Additionally, data collection for analyzing driving patterns ensures driver health and well-being through the concept of ‘truck driver persona’—a virtual representation based on a series of real data, abstracting the characteristics of a real user.

Autonomous trucks could also help alleviate the driver shortage by requiring less human intervention compared to traditional trucks. Nevertheless, there are considerable challenges to address, such as battery efficiency, which limits the viability of electric trucks for long-haul routes. Additionally, social acceptance and the need for a workforce with advanced technological skills pose hurdles to the adoption of autonomous trucks. Another critical issue is the development of charging infrastructure, which must be expanded and upgraded to meet the increasing demand for electric truck charging stations, necessitating significant investment and strategic planning.

These findings suggest that safety will remain a key priority within the social factor, driving the adoption of advanced technologies such as TIMs, predictive analytics, and AI to improve road safety. Although these innovations could influence vehicular traffic, they are expected also to speed up traffic when CVs and ATs are present. Introducing policies to reduce emissions, such as emissions taxes and subsidies for clean energy, may face resistance from drivers, managers, and owners. This information can be used to develop targeted interventions that facilitate adaptation to new trends, address resistance, and ensure a smooth and beneficial transition for everyone involved in the sector.

The evidence from this study suggests that, in the environmental field, emissions from heavy trucks and their impact on pollution remain a significant concern. To address this problem, various strategies are being explored, such as improving fuel efficiency, using algorithms to optimize travel times, and evaluating different energy sources. These results suggest that electric trucks stand out among these alternatives because of their potential to reduce the environmental footprint significantly. However, they also pose challenges, including battery efficiency, charging infrastructure, and acquisition costs, which must be addressed for this option to become a viable and sustainable solution.

These findings have significant implications for how stakeholders and policymakers should approach the following: policymakers face the challenge of developing and enforcing regulations that support alternative energies, including fiscal incentives, subsidies, and infrastructure investments such as charging stations. Transport companies and manufacturers will encounter higher costs for developing and producing alternative fuels, as well as the need to adapt processes and train staff. Early adoption of these technologies may offer competitive advantages, whereas delays could hinder the ability to keep up with industry advancements. Energy providers must adapt to new supply demands and invest in the necessary infrastructure to support alternative fuels. Overall, stakeholders must strategically address these challenges to effectively manage the transition and seize emerging opportunities.

The study contributes to our understanding of the economic aspects for trucking companies, highlighting that they will continue facing significant challenges, such as rising fuel prices, the cost of implementing new technologies, and the need for staff training. Emerging alternatives, such as natural gas, hydrogen, and biofuels, offer promising solutions, while strategies such as speed reduction can contribute to lower fuel consumption. The research has also shown that technologies such as autonomous trucks, AI algorithms, and smart GPS have the potential to improve efficiency and reduce costs. However, their adoption and economic impact vary depending on the company's size. Transportation automation is expected to increase efficiency but will also impact labor and operating costs, requiring strategic adaptation to balance technology investment with effective resource management.

This study has identified that in the political and legal factors, critical needs and challenges emerge. There is a growing demand for regulations and policies that support the transition to cleaner alternative energies, such as subsidies to boost the adoption of sustainable technologies. It is vital to encourage investment in the construction and modernization of road infrastructure to improve transport efficiency. The results of this research support the idea that it is essential for truck drivers to manage the change in the labor market, facilitating their transition to new employment opportunities in a fair and supportive manner. This requires the implementation of policies that promote training and reemployment, ensuring effective adaptation to transformations in the sector.

The benefits that companies, practitioners, and policymakers can gain from these results are outlined as follows:

- Electric and autonomous trucks are significantly impacting the transportation system, necessitating more infrastructure and modernization requirements.
- AI algorithms are increasingly important in accident prevention and route planning.
- Addressing new trends is crucial to reducing social resistance, which can be achieved through synergy among companies, governments, and manufacturers.
- From an environmental perspective, decarbonization plans are introducing alternatives to fossil-based energy sources. This represents a major challenge for distribution networks, charging stations, and implementation policies.
- Companies' economic situations will be influenced by emission reduction policies, subsidies for alternative energy implementation, adoption of emerging technologies like electric trucks, AI algorithms, and staff training in new technologies.

- Industry policies are being updated to align with sector needs, including alternative energies, relevant taxes and subsidies for their adoption, cybersecurity policies to protect privacy, and policies for technology access.
- The elements in each factor impact more than one factor. Infrastructure is a trend that is impacting technology, social, environment, and policy.

We are confident that this study will be highly valuable for practitioners, companies, and researchers who are preparing for the challenges and opportunities facing the road transport industry.

### **5. 1. Study limitations and future research work**

The limitations of the study are listed below:

- One limitation is that the study was conducted in a generalized manner. A more focused study could accurately represent the industry's situation in a specific region, with recommendations tailored to that area, such as a country.
- Another limitation was the limited information on currently implemented policies in the industry sector due to the search criteria used.
- Additionally, the proposed framework was developed solely based on data from the literature review. Incorporating information from other sources could offer a broader perspective.

The five factors identified by the PESTLE analysis could be the basis for developing an Impact Matrix Cross-Reference Multiplication Applied to a Classification (MICMAC) analysis. The next phase of the study is to validate the model through a verification process with government, industry, and academic experts. A universal application is also advised because the proposed framework was created using literature from several countries. However, further validation, quantification, and analysis were beyond the scope of this study.

For future studies, this framework might be the basis for developing MICMAC analysis, which analyzes the interrelationships and causal relationships among the factors, provides insights into their orientation and strength, and reveals their interdependent causal relationships. This method is often used in decision-making processes to prioritize the factors based on their impact. It has been applied in various fields, such as the supply chain, food sector, higher education, and agricultural systems (Barati et al., 2019; Kundu & Perwez, 2022; Priyadarshini et al., 2022; Usmani et al., 2022)].

Since the results of the PESTLE analysis could serve as guidelines for designing a MICMAC, the judgment of experts in the field can shed new light on it. Future research will also shed new light on policy and decision-making and help shape the trucking industry's future, such as:

- Evaluate the impact of different technologies on the trucking industry and society.
- Analyze the progress and future of alternative fuels and their implementation in the coming years.
- Conduct a case study on the implementation of ATs in developing countries where the adoption of these technologies is just beginning.
- Analyze the evolution of policies concerning new technologies.
- Assess current programs and incentives aimed at promoting innovation within companies.

Future research will bring new light to policy and decision-making and help shape the trucking industry.

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## Author contribution statement

Conception and design: PTN and DGC; analysis and interpretation of the data: PTN, DGC, ACC, and AEN; drafting of the paper: PTN, DGC, ACC; revising it critically for intellectual content: PTN DGC; and final approval of the version to be published: PTN, DGC, ACC, and AEN.

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## Data availability statement

The data that support the findings of this study are available in Google Scholar at <https://scholar.google.com/>, Scopus at <https://www.scopus.com/search/form.uri?display=advanced>, and Web of Science at <https://www.webofscience.com/wos/woscc/advanced-search>. The data that support the findings of this study are available from the corresponding author, DGC, upon reasonable request.

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