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Charging Ahead: Economic and Logistical Considerations for the Electric Freight Transition in South Texas

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ABSTRACT: Freight tonnage transported in the U.S. is projected to grow by 1.6% annually between 2023 and 2050 (Bureau of Transportation Statistics 2024). The electrification of truck freight transportation is essential for meeting emission reduction targets (Hoehne et al. 2023). The prospect of widespread battery electric truck adoption has continued to improve due to public and private investment, technology advancement, cost-benefit enhancement, and policy support. The implications for South Texas are significant due to the region's strategic geographic location and reliance on the freight industry. Recent research has shown that electric freight vehicles enable substantial cost and environmental advantages compared to diesel alternatives (Phadke et al. 2021). Limited charging infrastructure and high initial costs present significant barriers to the adoption of electric freight trucks in South Texas. This paper explores the economic and logistical challenges to electric freight truck adoption in South Texas and discusses the implications for policymakers to consider, including strategies for improving infrastructure, reducing costs, and supporting industry adoption. Solving the challenges of infrastructure and technological advancement is crucial for realizing the full potential of electric freight in South Texas, both operationally and economically. This paper highlights the need for greater coordination among industry leaders, policymakers, and regulators to address these barriers, paving the way for a successful transition and setting a model for future freight transportation.

KEYWORDS: Freight electrification, charging infrastructure, sustainable transportation, electric trucks

Introduction

Transportation accounts for 24% of global greenhouse gas emissions (Nair et al. 2024) and is consistently cited as a critical focus area from a regulatory perspective. Sustainable transportation has become a central theme of the multifaceted decarbonization conversation. The urgency to reduce emissions and mitigate climate change impacts is evidenced by the increased commitments by global organizations and regulatory bodies to address the issue. Economic and population growth trends have also expanded the transportation industry, resulting in higher energy consumption requirements and greenhouse emissions (Yao et al. 2023). A comprehensive approach to mitigating the industry's reliance on fossil fuels is imperative to achieve significant emission reduction objectives.

Electric vehicles have increasingly been perceived as a viable solution to achieve sustainable transportation systems. A bibliometric analysis by Pandey and Shalu (2023) found strong support from prominent academic journals for sustainable transport to mitigate increasing pollution levels on a global scale. Since 2020, substantial federal and state initiatives have been implemented to incentivize electric vehicle adoption in the United States. This includes federal tax credits, state-level rebates, and charging infrastructure support for states. Investments from the 2021 Infrastructure Investment and Jobs Act and the 2022 Inflation Reduction Act in the U.S. have encouraged the expansion of electric vehicle manufacturing and enabled a more significant deployment of electric transportation technologies (Nigro et al. 2023). The resulting increase in public and private investment in electric vehicles and charging infrastructure facilitates widespread adoption at an increased rate. Regional transportation hubs play an essential role in electrifying freight transportation and enhancing the effectiveness of investment and policy support. South Texas benefits from its strategic geographic location and shared borders with Mexico, facilitating international trade. The electrification of heavy long-haul trucks transporting goods from the border to their final destinations presents a considerable challenge. The stress on the electric grid and associated charging infrastructure requires substantial economic and time investment (Dong et al. 2021). Furthermore, travel distances and timely delivery of goods to meet demand underscore the importance of operational reliability. Understanding electrification requirements to address the industry's specific needs in the region is fundamental in accelerating adoption rates.

Government incentives and policies are essential to the transition to electric transportation technologies. Consequently, electric vehicle growth expectations convey a general sense of optimism. Globally, the electric vehicle market is expected to expand at a compounded annual growth rate of 16.4% from 2022 to 2029 (NASDAQ OMX 2022). In North America, the commercial electric vehicle market is expected to grow an excess of 45% compound annual growth rate, driven by factors such as demand in the logistics industry, financial adoption incentives, falling fuel and maintenance costs, and current pollution standards. Transitioning to an electrified commercial transportation system remains critical to achieving emission reduction targets, as medium- and heavy-duty vehicles account for 40% of transportation-related emissions globally (Brown et al. 2020). However, significant adoption challenges exist.

Prominent commercial freight vehicle manufacturers seek to capitalize on the adoption trend of electric vehicles. Freightliner recently introduced its eCascadia electric semi-truck. The manufacturer claims that the electric model is ready to move the world toward cleaner, quieter, and more efficient operations, helping organizations meet their sustainability goals (Freightliner n.d.). Volvo Trucks is currently advertising eight distinct semi-truck models for various operational applications. The company’s stated goal is to make the shift to electric trucks as smooth as possible (Volvo Trucks 2024). A commonality between both manufacturers is the limited battery range of their current models, advertised between 190 miles and 230 miles per charge. Tesla, a prominent participant in the electric vehicle industry, has recently introduced a semi-truck model to their lineup. The company advertises a range of approximately 300 to 500 miles with a full cargo (Tesla 2024). The practical deployment of electric freight vehicles to meet the freight transportation needs in South Texas is crucial to achieving a sustainable transportation system in the region. Factors affecting adoption include vehicle availability, range, charging infrastructure, and haul capacity. Long-haul trucks typically travel over 100,000 miles yearly and are designed to travel long distances (Fleming et al. 2021). Technical capabilities of electric trucks and the associated charging technologies necessitate minimal charging downtime, sufficient range to reduce stops, and comparable payload capacity to diesel alternatives to effectively address the operational needs of the industry in the region. A deep examination of the regional challenges impacting the practical integration of electric freight vehicles can uncover shortfalls and identify focus areas.

Freight transportation continues to accelerate in the United States. The demand for freight transportation is primarily driven by the geographic distribution of the country's population and economic activity (Najafi et al. 2024). The movement of goods relies on the effective and efficient consolidation of supply chains and associated channels. Due to its shared border with Mexico, South Texas is a vital artery for international trade and is essential for linking markets and fueling economic growth (German 2023). Texas supply chains for critical manufacturing industries are integrated with factories in Mexico that produce individual parts required for manufacturing processes in the U.S. or assemble components into finished products (Texas Department of Transportation 2023). According to TxDOT (2023), 49.3 million tons of freight worth $249.2B entered Texas from Mexico by truck or rail. In 2023, the World Trade Bridge, the Colombia Solidarity Bridge, and the Laredo International Railway Bridge in Laredo, Texas, overtook Chicago O-Hare airport and the seaport of Los Angeles to become the United States’ number one port of entry by total trade (TAMIU, 2024). South Texas is highly dependent on the transportation industry, as evidenced by the 28% gain in general freight trucking jobs in the 10-year period ending 2022 (Texas Comptroller of Public Accounts 2024). Additionally, trade from Mexico is expected to increase robustly in the long term, supported by a recovery of the U.S. economy, a continuation of Mexico's robust manufacturing sector, and nearshoring activities (Fitch Solution Group Limited 2024). South Texas is at the forefront of the industry and its electrification initiatives due to the expanding need for freight capacity in strategic geographical locations to meet the expected growth in demand and the region's reliance on transportation.

At present, the freight transportation industry is heavily reliant on fossil fuels, which exacerbates its contributions to global emissions. Transportation truck fuel consumption increased by 7.2% from 2012 to 2022, while miles travel increased substantially by 22.4%, capturing 26% of all gasoline, diesel, and other fuel consumption in the United States (Bureau of Transportation Statistics 2024). The disproportional increase in miles traveled relative to the rise in fuel consumption may be attributable to fuel efficiency efforts to reduce emissions. However, in addition to carbon monoxide, nitrogen oxide, and particulate matter emissions, transportation was responsible for approximately 28.0% of all greenhouse gases emitted in the United States in 2022 (Bureau of Transportation Statistics 2024). The rising fuel consumption and related industry pollution consistency evidence the limitations of fuel efficiency as a sole initiative to address emissions.

Electric freight vehicles represent a scalable solution to address industry emissions. Electric transportation enables renewable energy charging options such as photovoltaic and eolian energy to achieve zero-emission transportation. However, truck electrification's benefits depend on the intensity of emissions of the electricity generation mix used to charge the truck's batteries. The only scenario that shows negative incremental environmental benefits relative to diesel is when electricity is entirely sourced from coal-based generation (Phadke et al. 2021). Nonetheless, from 2008 to 2018, only 7% of new electric generation capacity was coal in the United States. Conversely, 44% of new capacity additions in the same timeframe were wind and solar. The integration of renewable energy will also require energy storage to minimize the electricity generation and power capacity variability inherent to renewable energy sources. Additionally, a charging infrastructure that provides comparable charging accessibility and reliability to conventional fueling stations is imperative. The current range limitations of electric freight vehicle batteries call for an adequate logistical network to prevent operational issues.

Realizing the environmental benefits of large-scale electric truck adoption requires evident cost competitiveness with conventional internal combustion engine alternatives to incentivize adoption. Cost justification is achieved by combining truck productivity and charging strategies, resulting in cost-efficient charging to minimize variable operating costs. Primary economic factors considered in the decision-making process for battery electric truck procurement include the total cost of ownership and operational and maintenance expenses (Ozlu and Celebi 2024). Furthermore, battery electric trucks' cost performance depends on balancing their decreased variable operating costs against the higher initial investment required for battery and charging infrastructure (Engholm et al. 2024). Government incentives and adoption programs can significantly reduce the latter, improving payback times for freight companies and fleet operators.

The transition to electric freight transportation is recognized as an essential focus area for achieving global greenhouse gas reduction goals. However, this transition presents critical logistical and economic challenges that may vary by region. While logistical efficiency can be achieved by strategically maximizing the placement of charging stations within existing infrastructure (Husinec et al. 2024), questions regarding the impact on fleet logistics, total cost of ownership, and range anxiety remain (Lohawala and Spiller 2023). The inability to address such questions deters adoption rates by preventing stakeholders from clearly understanding the associated operational and investment requirements.

The multifaceted efforts to increase electric freight adoption and related expectations need to be analyzed from a practical perspective for specific geographical regions. Developing a regional analysis is particularly important for critical transportation hubs such as South Texas. A critical examination of regional logistical and economic factors provides the understanding needed for effective and prompt infrastructure enhancement, policy and economic incentive implementation, and targeted adopter awareness programs.

The purpose of this paper is to analyze and synthesize existing literature on the economic and logistical factors influencing electric freight truck adoption in South Texas. The synthesis provides practical regional considerations essential to truck electrification that remain unaddressed by the existing body of literature. This paper argues that while transitioning to electric freight transportation in South Texas presents significant economic and logistical challenges, strategic planning and supportive policies can facilitate a successful and sustainable transition.

Literature Review

Overview of Electric Freight Transportation

The global transition to electric freight vehicles has been partially driven by nations' commitments to decarbonize transportation. The transportation sector is a significant source of global greenhouse gas emissions. Heavy-duty trucks are a primary oil consumer in road cargo transportation, placing this segment at the forefront of global efforts to reduce emissions (Ozlu and Celebi 2024). In the Paris Agreement, China pledged to achieve carbon neutrality, or the state in which the greenhouse gases entering and exiting the atmosphere are in equilibrium, by 2060 (Yan and Jiang 2023). The European Emission Trading System legislative framework was amended for phase four in 2018 to achieve the EU's 2030 emissions reduction target of 40% relative to their emissions in 1990 and their commitment to the Paris Agreement (Bhardwaj and Mostofi 2022). India has also pledged to cut greenhouse gas emissions by 33 to 35% relative to 2005 by 2030 and achieve net-zero emissions by 2070 (Zhang et al. 2023). The U.S. set its new nationally determined contribution to achieving economy-wide reductions in greenhouse gas emissions of 50 to 52% below 2005 levels by 2030 (Yuan et al. 2022). However, only 60,000 units, representing 1.2% of sales worldwide, were electric medium- and heavy-duty trucks in 2022 (IEA 2023) despite the combination of these commitments and the current maturity of electric truck powertrain and related technology. Three conditions are needed for the widespread success of battery-electric trucks, including the right technology and products, appropriate refueling infrastructure, and a cost-effective ownership model (Institute of Transportation Engineers 2024). Public and private initiatives to address these conditions can improve adoption rates in regional transportation hubs, such as South Texas.

Recent studies and industry reports highlight the general advantages of adopting electric freight vehicles. In the International Energy Agency's net-zero by 2050 scenario, transportation emissions are reduced by 90% between 2020 and 2050 despite rapidly growing freight activity, enabled by policies to promote mode shifts, improvements in vehicle efficiency and systems operations, use of low-carbon fuels, and widespread electrification (Hoehne et al. 2023). According to a stakeholder analysis by Muller (2023), replacing conventional trucks depends heavily on the economic conditions and the resulting willingness to invest in new fleets. From a cost perspective, Burke et al. (2022) found that most battery-electric commercial trucks' total cost of ownership competitiveness will occur by 2025, and battery range and recharging considerations can further improve cost. Furthermore, battery electric long-haul trailers could compete with diesel trucks and offer a more significant economic advantage in a high-priced diesel market environment (Karlsson and Grauers, 2023). The volatility of traditional fuel prices enhances the competitive argument presented by electric trucks. Addressing the charging price uncertainty from various battery capacity and charging strategy scenarios remains critical to truck electrification. This is especially true for transportation corridors that enable vital supply chains.

Economic Considerations

Transitioning to electric truck technologies necessitates cost competitiveness relative to traditional fuel alternatives. Phadke et al. (2021) researched long-haul electric truck economics using a bottom-up cost, weight, and performance estimation. Batteries were the main contributor to the higher capital cost of electric trucks. However, the cost of electric powertrains was less than a third compared to diesel counterparts (Phadke et al. 2021). The total cost of ownership is presented on a per-mile basis, summing the unit capital cost, maintenance cost, fuel cost, and general operation. The study found that a class 8 electric truck with a 375-mile maximum range and a daily average utilization of 300 miles offers approximately 13% lower total cost of ownership. This translates to a 3- to 4-year payback period and an estimated $200,000 in net savings over its lifetime with a minimal payload reduction. The findings by Bhardwaj and Mostofi (2022) suggest that electric trucks present a total cost of ownership of approximately 26% less than diesel vehicles in a short-term scenario ending in 2030. Similar conclusions have been proposed by Sharpe and Basma (2022), referencing a 31% and 55% decrease in electric truck battery packs and electric drive units by 2025 and 2030, respectively.

The acquisition cost of electric trucks is significantly higher at present. The economic model by Phadke et al. (2021) suggests an estimated 69% to 97% higher upfront cost for electric trucks relative to diesel trucks. The incremental capital cost of an electric truck is mainly attributed to its associated battery cost (Bhardwaj and Mostofi 2022). However, lower maintenance and fuel costs associated with electric transportation technologies provide a clear economic advantage. The average maintenance cost across key studies in the U.S. for battery electric vehicles is $0.05 to $0.10 per mile lower than diesel trucks (Wang et al. 2022). Similarly, average electricity rates are estimated at $0.10 to $0.17 per kWh for at-base charging compared to near-term diesel prices of $3 to $4 per gallon.

Logistical Challenges

Logistical hurdles deter the transition to electric freight transportation. Currently, significant charging infrastructure limitations exist. According to Al-Hanahi et al. (2021), the restricted capacity of some electrical power infrastructure limits charging rates, resulting in multiple charging events to meet a truck's daily travel requirements. As a result, availability and the practical feasibility of fast charging are critical (Nykvist and Olsson 2021). Medium-duty commercial vehicles cover an average daily travel distance of 80 to 250 kilometers. In contrast, heavy-duty counterparts may average 700 daily kilometers (Al-Hanahi et al. 2021). Thus, charging rates and the charging events required to sustain daily travel distances underscore the importance of adequate infrastructure. Furthermore, the power capacity for charging depots is considerable due to the large batteries associated with medium- and heavy-duty freight trucks, and faster chargers can cost up to $175,000 per unit (Lohawala and Spiller 2023).

Cheng and Lin (2024) identified public rest areas along the highways and truck stops as potential siting solutions for charging stations. The spatial density and coverage of these areas were determined to be ideal for electric truck chargers. The study found that electric trucks increase journey time between about 16% to 31% due to charging activities. However, the service rate, or charging station capacity, and associated charging time of designated charging areas profoundly impact operational feasibility. A service rate of 3 trucks per hour, or 20 minutes per charging service, yields substantially reduced waiting times compared to a service rate of 0.5 trucks per hour (Cheng and Lin 2024); a higher battery capacity further reduces induced delays.

Integrating electric truck technologies to replace diesel alternatives requires significant electricity generation, transmission, and distribution investments (Lohawala and Spiller 2023). According to Konstantinou et al. (2023), a resilient grid is essential to electric truck adoption, and policymakers should coordinate with grid operators, utilities, and researchers to accommodate the electricity demand from a high volume of electric trucks. Such actions include grid expansion investments, improved grid management, time-of-use incentives, strategic deployment of charging stations, enhancing vehicle-to-grid capabilities, and increasing technical feasibility awareness.

Policy and Incentive Programs

In the U.S., the Inflation Reduction Act and the Infrastructure Investment and Jobs Act contain provisions to advance electric truck adoption. The former promotes the integration of renewable energy sources into the grid, increasing electric generation capacity and the environmental benefits of greater electric truck adoption rates (Lohawala and Spiller 2023). An analysis by Mcneil et al. (2024) found that a low renewable energy cost scenario enables the electrification of 128 of 200 freight corridors. The number increases to 188 freight corridors with the inclusion of the Inflation Reduction Act. The primary incentive mechanism is investment tax credits. Conversely, the Infrastructure Investment and Jobs Act provides funds for public charging station investment, funding and accelerated siting approvals for electric transmission expansion, and funds to improve grid resilience (Lohawala and Spiller 2023).

The National Electric Vehicle Infrastructure Program, a primary provision of the Infrastructure Investment and Jobs Act, allocates $5.4B USD to fund all U.S. states and support electric vehicle charging infrastructure across interstates and highways (Institute of Transportation Engineers 2023). However, current plans proposed by the Texas Department of Transportation (2023) under the National Electric Vehicle Infrastructure Program omit freight charging, pending guidance from the Federal Highway Administration. Conversely, the U.S. Department of Transportation has requested stakeholder input to address the charging technologies and infrastructure needs for medium- and heavy-duty vehicles (U.S. Department of Transportation 2024). Notably, the National Zero-Emission Freight Corridor Strategy report by Chu et al. (2024) proposed a four-phased infrastructure development approach prioritizing established transportation hubs, including South Texas. Subsequent phases connect, expand, and complete the infrastructure network. The initial phase of this strategy is projected to span three years, from 2024 to 2027 (Chu et al. 2024).

Technological Advancements

The development of heavy-duty vehicles, trucks, and buses has recently enabled commercial availability on a global scale (Harrison et al. 2023). Battery electric trucks had not previously been considered a viable option to replace diesel heavy-duty trucks due to their high energy requirements relative to the low energy density of past battery technologies (Liimatainen et al. 2019). However, recent developments in battery technology are making electric heavy-duty trucks technically and commercially viable. The IEA (2023) estimated a 6% increase in the average battery capacity in heavy-duty vehicle models from 2019 to 2022. The steadily rising energy density of batteries has also reduced electric truck weight, minimizing payload differences relative to diesel (Phadke et al. 2021). A study by Bhardwaj and Mostofi (2022) claims that the conditions for battery-electric trucks have significantly changed, with a battery cost reduction of 89% or $137/kWh in 2020, relative to $1100/kWh in 2010. The authors also referenced improving fast-charging technologies from manufacturers such as Tesla, MAN trucks, and Freightliner as critical technical aspects of battery electric trucks. The significant drop in battery costs enhances acquisition costs while charging technologies and battery energy density increase operational feasibility. Furthermore, the battery electric truck model market is experiencing rapid growth, with over 70 models under development across classes (Fleming et al. 2021). Significant truck electrification efforts are closing the technological gap and are expected to increase market acceptance

The successful integration of electric trucks relies on technological solutions that reduce the barriers associated with logistical factors. Lohawala and Spiller (2023) proposed managed charging, vehicle-to-grid technology, co-located storage and solar, and battery swapping as integration methods. Managed charging relies on software to optimize charging patterns with a particular purpose, such as reducing maximum demands during peak hours or decreasing operating costs (Lohawala and Spiller 2023). As a result, electric truck integration investments may be reduced by up to 62 percent. Similarly, vehicle-to-grid technologies enable bi-directional electricity flows in exchange for potential economic compensation to fleet owners (Lohawala and Spiller 2023), enabling grid stabilization.

Discussion

Transitioning to electric trucks in South Texas enables substantial environmental and economic benefits. However, the resulting integration investment from an economic and logistical perspective poses significant challenges. Electric trucks' current upfront costs are substantially higher than diesel alternatives, and the existing charging infrastructure along major transportation corridors in South Texas remains inadequate. As a result, critical reductions in the total cost of ownership associated with electric trucks are uncertain and limited. The savings potential and associated environmental benefits from electric trucks in the region are dependent on technological and infrastructure development and advancement. The adoption rate will remain low until these challenges are mitigated.

Operational models enabled by electric trucks can create significant economic benefits for fleet operators. Complementary technologies, such as managed charging and vehicle-to-grid capabilities, unlock further charging cost savings and revenue models. Additional benefits include reduced stress on the existing grid infrastructure, optimized charging service, and enhanced integration. Further development and commercialization of these technologies are critical to achieving electric truck adoption rates in South Texas. Increasingly higher battery densities and reduced battery costs enhance operational and economic feasibility, resulting in improved business models. Technological improvements continue to develop at an accelerated rate but require increased stakeholder coordination to ensure prompt and efficient integration.

Recent policy initiatives partially bridge the cost gap between electric trucks and diesel alternatives. Tax incentives substantially increase the cost competitiveness of electric trucks, and public funds are expected to accelerate the development of charging infrastructure. However, enacted policy prioritizes the development of charging infrastructure for passenger vehicles, and critical provisions rely on prompt planning by state transportation agencies. TxDOT's charging infrastructure plans enhance the integration of electric passenger vehicles but fail to address commercial transportation, pending USDOT guidance. As a result, the design of charging sites may lack adequate power capacity and design elements for electric truck charging. Delayed integration of electric truck charging infrastructure impedes adoption by limiting the ability of electric trucks to transport goods over longer distances. Additionally, a site retrofit approach requires higher investment, further planning, and introduces potential design barriers. Expedited guidance from USDOT and prompt coordination with state agencies are required to achieve efficient infrastructure development and maximize funds.

Conclusion

This paper explores the economic and logistical challenges to electric freight truck adoption in South Texas and discusses the implications for policymakers to consider, including strategies for improving infrastructure, reducing costs, and supporting industry adoption. An overarching finding is the need for greater coordination between policymakers, federal and state agencies, and industry leaders. Current legislation provides the necessary funds to develop the charging infrastructure and electric generation capacity for electric vehicle integration but lacks specific commercial transportation guidance for state agencies, resulting in induced adoption delays. Policymakers must prioritize coordination with industry representatives to develop effective guidelines for commercial vehicle charging infrastructure.

Available technologies, such as managed charging, facilitate widespread electric truck integration into the existing electric grid, enabling faster adoption. The continued advancement of associated technologies and prompt charging infrastructure development benefit electric trucks' cost performance. Policy and regulation should promote further charging technology development and integration by facilitating access to pertinent data, promoting industry collaboration, and providing research funds for further battery and charging technology developments.

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