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# The Road Ahead for Electric Vehicles (EVs) in Developing Countries: Market Growth, Infrastructure, and Policy Needs

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Posted Date: 28 January 2025

doi: 10.20944/preprints202501.2083.v1

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*Article*

# The Road Ahead for Electric Vehicles (EVs) in Developing Countries: Market Growth, Infrastructure, and Policy Needs

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**Abstract:** Developing nations like Bangladesh have yet to adopt hybrid electrical vehicles (EVs) for goods carrying causes, whereas environmental pollution and fuel costs are hitting hard. The electrically powered cars and trucks market promises an excellent opportunity for environmentally friendly transportation. However, these countries' inadequate infrastructure, substantial initial expenses, and insufficient policies impeding widespread acceptance hold market growth back. This paper examines the current status of the electric car market in developing nations, focusing on the infrastructure and regulatory framework-related barriers and the growth-promoting aspects. To promote an expanding hybrid and EV ecosystem, this article outlines recent studies and identifies critical regions where support for policy and infrastructural developments are needed. It discusses how developing nations may adapt successful international practices to suit their specific needs. At the same time, the research adopted system dynamics and case study methods to assess a transportation fleet and find the feasibility of adopting EVs. Several instances are improving infrastructures for recharging, providing incentives for lowering the adoption process cost and creating appropriate regulatory structures that promote corporate and consumer involvement. Findings highlight how crucial it is for governments, businesses, customers, and international bodies to collaborate with each other to build an affordable and sustainable EV network. The investigation concludes with recommendations for more research and appropriate regulations that may accelerate the adoption of EVs, reduce their adverse impacts on the environment, and promote economic growth.

**Keywords:** electric vehicles; hybrid; developing countries; market growth; infrastructure; policy; Bangladesh

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## Introduction

**Background on EV adoption globally and challenges in developing countries.**

Electric vehicles have emerged as a pivotal technology in reducing global greenhouse gas emissions [1], combating climate change, and transitioning toward sustainable transportation systems [2]. In 2022, global EV sales exceeded 10 million units, marking a 55% increase from the previous year and accounting for 14% of all new car sales [3]. For instance, Norway, China, and the United States have adopted EV vehicles driven by comprehensive policy frameworks and innovative technologies [4]. At the same time, they incorporate public and private investments in infrastructure development. Specifically, Norway aims to achieve over 80% of its EV market share in 2022, reinforced and supported by zero carbon emission zones and a nationwide charging system [5].

In contrast, EV adoption is still in the infant stage due to a lack of infrastructure, accessibility, customer ignorance, and confidence [6]. People are unaware of how charging networks will work for them without electricity [7]. Besides, potential customers are heavily price-sensitive and highly

 doi:10.20944/preprints202501.2083.v1



concerned about EVs' high upfront costs [8]. Such matters worsened the EV implication in light of the lack of local investors and production, which ultimately rely on imports only. Inadequate government assistance, tax, and policy support, exemplified by incoherent relevant carbon emission laws, insufficient incentives, and unplanned national vision, is another issue facing developing countries [9].

Socio-economic differences further complicate the adoption of Evs by different social classes [10]. In developing countries, the basic need for electricity cannot maintain its 24/7 continuity due to a shortage of resources, technologies, conventional grid systems, and inefficient workers [11]. Again, income inequalities among different social classes, such as the rich, middle-class, and poor, or urban and rural areas, limit EV adoption. Urban elites have the money, but they do not have enough concern about futuristic scenarios and carbon emissions. Furthermore, most developing countries rely on coal-based electricity generation, which increases environmental concerns. At the same time, several developing countries like Bangladesh adopted quick rental electricity through private sectors producing electricity using fossil fuel, condensed natural gas (CNG), and coal to support the government-owned electricity grid. Such initiatives provide temporary solutions but increase costs and carbon emissions as they focus on supply rather than environmental damages. To reduce emissions, EVS can help the community by requiring less electricity and developing much greener energy initiatives [45]. In this scenario, policymakers must establish relevant policies [46] and construct laws encouraging people to consider electronic vehicles. To gain popularity among the citizens, a country needs adequate investments in renewable energy, reasonably priced EV vehicles, and public-private partnerships, which are vital to encourage sustainable EV adoption in these areas.

**Problem-identifying barriers to EV adoption.**

The adoption of EVs faces notable barriers in developing countries, hindering potential transformation toward environmentally friendly sustainable transportation. Many countries are already eradicating environmental problems through hybrid and EVs to reduce carbon emissions. Carbon emissions are primarily sources from industries and vehicles that use fossil fuels as a burning resource and generate power supplies for their daily operations. The world produces more than 37 billion tonnes of carbon through these processes that have never been healed through natural and artificial processes. The environmental loads are piling up daily, creating atmospheric changes for adverse climate changes. At the same time, conventional structure, economic status, and policy challenges impede widespread adoption.

I. Policy and Regulatory Barriers [12]: Developing countries often lack consistent countrywide innovative strategies to promote any transformation like EVs, resulting in disjointed policies and weak incentives. Developing nations always respond to any transformations due to a lack of scientific knowledge practices and are afraid of federal interventions for subsidies. Any developing Governments commonly fail to support adequate subsidies, tax rebates, and breaks, or any other types of financial motivations to inspire EV consumption and infrastructure change. This policy and regulatory vacuum demoralize private entrepreneurs from stepping forward to invest and adopt new processes for transformed products like EVs.

II. Inadequate infrastructure [13,14]: The second barrier is establishing a new structure for charging stations and making it accessible to urban and rural areas. Most developing nations face unstable electricity supplies, too, making things challenging for highly electricity-reliable vehicles. Such infrastructural inefficiency decreases potential consumer confidence and confines the feasibility of EV usage, mainly in rural and semi-urban areas.

III. Economic Challenges [14,15]: EVs need high upfront costs, which are unaffordable for middle-class people in developing nations. The current practice is to produce fossil fuel vehicles through local manufacturing and assembly industries depending on imported vehicles. They used to get dual financial support from car manufacturers, dealers, and financial institutions to handle overly price-sensitive markets. Additionally, the limited availability of such reasonable financing options restricts EV selling toward higher and moderate-income groups, excluding the mass population living under the poverty line.

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IV. Environmental Concerns [14–16]: Developing countries' worrying reliance on fossil-fuel-based electricity undermines innovative electric vehicles' environmental paybacks. Such standard practices create skepticism about EVs' overall impact. Without a transition to cleaner energy sources, EV adoption may not achieve its intended sustainability goals.

V. Limited Buyer Awareness and Trust [13,17]: Before a customer makes a buying decision, they have to have enough understanding of the product features. People in developing countries lack understanding and education on EV features, benefits, maintenance knowledge, finance requirements, and long-term savings calculations. Such awareness creates hesitancy in adopting EVs. Many misconceptions about EV reliability, weather sensitivity, battery lifespan, and upfront costs further diminish consumer trust.

VI. Technological Gaps and Supply Chain Constraints [18,19]: Developing countries rely heavily on importing technologies rather than innovating them in their own countries. Such limitations create challenges in accessing unconventional EV technologies due to supply chain limitations and the high import cost of essential vehicle components. For instance, the Bangladesh government imposes 600-800 percent taxes for luxury vehicles, which restricts the affordability of high-quality EVs in local markets.

VII. Urban-Rural Disparities [20]: In developing countries, most facilities are concentrated in major cities, and the rest struggle to have minimal facilities like roads and highways, high-end product accessibility, maintenance and repair facilities, and charging infrastructure. Moreover, EV-related customer services are often located in urban areas, leaving rural areas underserved. This discrepancy limits the spread of EV adoption to regions with improved infrastructure and financial resources.

Thus, the above barriers highlight limited global practice adaptability to developing countries. Despite the worldwide momentum toward adopting EVs, the transferability of efficacious practices from developed to developing nations remains inadequate. Developed countries like Norway and the Netherlands have applied robust policy agendas, widespread charging infrastructure, and monetary incentives, motivating EV adoption. However, these models may not work for developing countries due to their unorganized socio-economic and infrastructural conditions, creating a noteworthy research gap. Developing countries face fundamental challenges such as conventional power grids, urban-rural budget divides, and imperfect local manufacturing capabilities for EVs and their maintenance. These issues render many globally successful strategies, such as extensive subsidies or reliance on high-cost charging networks, unsuitable or unsustainable in these regions. Additionally, the high dependency on coal-based energy in developing countries reduces the environmental benefits of EVs, a factor often overlooked in global practices. While existing studies highlight the effectiveness of policies like tax rebates and infrastructure investment in developed economies, little research focuses on how these measures can be tailored to developing countries' financial, infrastructural, and cultural realities. This research gap underlines the importance of local strategies and policies for the specific challenges related to switching to efficient EV technologies in regions with limited resources.

Based on the above discussions, this study comprehensively examines the market challenges, potential, and solutions for EV adoption in developing countries. While EVs have immense potential as a sustainable, environment-friendly transportation alternative, developing countries face unique challenges that explain their limited implementation. This paper aims to discover these dynamics and present actionable perceptions to hasten EV market development. The objectives of the studies are as follows:

I. To examine EV adoption trends, challenges, and policy barriers in developing nations, highlighting market potential and identifying region-specific obstacles to widespread adoption. Analyzing barriers such as infrastructure limitations, high costs, and policy gaps alongside the potential of emerging EV markets driven by urbanization, environmental awareness, and a growing middle class.

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II. Build a System Dynamics simulation model on a transportation fleet case to examine costs, carbon emissions, revenues, fuel consumption, and maintenance expenses. Then, analyze and compare the current transportation scenario with hybrid and electric vehicle (EV) adoption to assess the operational, economic, and environmental impacts of adopting sustainable transportation solutions in fleet operations. It provides a possible scenario to identify key barriers and opportunities for sustainable fleet transitions.

III. To propose actionable recommendations and policy strategies for overcoming barriers and tailoring global EV adoption practices to developing nations' socio-economic and infrastructural contexts.

## Literature Review

### Overview of global EV adoption trends

The adoption of electric vehicles has skyrocketed because of technological advances, supportive policies, and consumer consciousness of environmentalism. The worldwide sales of EVs reached a record high of 10 million in 2022, up 55 percent from the previous year, while EVs gained a 14% market share. Government support, infrastructure, and financial variables affect geographical adoption tendencies. Table 1 highlights key global trends, adopted countries, instances, and features driving EV adoption. For example, Norway and China emphasize policy-driven growth based on government subsidies and tax exemptions, which are consequential in significant market shares. Infrastructure development, led by the USA and Germany, focuses on extensive charging networks combined with renewable energy networks. Cost advantage is crucial in countries like Southeast Asia and India, where affordable EV models provide economically price-sensitive customers. Urban-centric growth in Europe and Japan emphasizes shorter commutes and dense populations, whereas BYD and Tesla's technological advances promote innovative battery innovation and fully autonomous driving capabilities. Nevertheless, since both South Africa and India depend significantly on coal-based power, environmental advantages are reduced by coal-centric energy problems. Export-driven manufacturing, which South Korea and China primarily drive, spotlights competitive trade and manufacturing marketplaces, pushing the growth of EVs globally. These trends demonstrate an array of geographically specific strategies that strike an equilibrium between infrastructure, cost-effectiveness, and technology despite tackling environmental and economic challenges.

**Table 1.** key EV adoption trends, examples, and features:.

| Trend | Country | Features | Instance |
|---|---|---|---|
| Policy-driven Growth [12] | Norway, China | Government subsidies, tax exemptions, and stringent emission regulations. | Norway and China have achieved over 80% EV market share by offering incentives such as tax exemptions, toll-free access, and charging subsidies. |
| Infrastructure Expansion [13,14] | United States, Germany | Deployment of extensive charging networks and integration with renewable energy grids. | Germany and the US lead in charging network deployment, ensuring seamless long-distance travel for EV users. |
| Cost Competitiveness [21] | India, Southeast Asia | Introduction of affordable EV models targeting price-sensitive markets. | India and Southeast Asia focus on affordable EV models like two-wheelers and small cars, catering to price-sensitive populations. |
| Urban-centric | Europe, Japan | Focus on urban areas with high population | Europe prioritizes urban EV adoption due to dense populations and short commute |

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| | | | |
|---|---|---|---|
| Adoption [22] | | density and short commuting distances. | distances, where charging infrastructure is more feasible. |
| Technological Innovations [23] | Tesla (U.S.), BYD (China) | Advanced battery technologies, extended ranges, and integrated autonomous driving features. | Tesla has advanced battery technologies with the development of the 4680 battery cell, which offers higher energy density, extended vehicle range, and reduced production costs. |
| Coal-centric Power Challenges [24] | India, South Africa | High reliance on coal-based electricity, reducing the environmental benefits of EV adoption. | India heavily relies on coal-based electricity, with NTPC Limited as one of the largest coal power producers. |
| Export-driven Production [25] | China, South Korea | Dominance in global EV manufacturing and export markets, driven by competitive production. | China, led by companies like BYD, dominates the global EV manufacturing market through highly competitive production practices and state-backed incentives. |

**Infrastructure challenges in developing regions**

Infrastructure is an essential requirement for implementing any idea. Infrastructure is the main barrier to adopting EVs in developing countries. Such infrastructural challenges limit accessibility, trustworthiness, and consumer confidence, encumbering the transformation of environmentally friendly transportation. The most significant barriers to the widespread use of EVs in developing countries are presented in Table 2. EV usefulness is limited to the absence of charging infrastructure in nations like Bangladesh and Nigeria and frequent interruptions resulting from unstable power grids. In South Africa and India, weakened consumer confidence is due to the same problem. Due to dense charging infrastructure in cities, countryside regions have been squeezed out, as demonstrated by urban-rural inequalities in Kenya and Indonesia. EV adoption continues to be hindered by grid capacity constraints in countries like Vietnam and Pakistan, where overloaded infrastructures are unable to cope with increasing demands. The installation of required charging networks has been impeded because of high infrastructure expenses in Ghana and the Philippines due to a lack of financing. Ultimately, the absence of access to innovative recharging equipment in Uganda and Cambodia hampers EV adoption. These challenges draw attention to the organizational and systematic barriers that prevent EV adoption from becoming widespread in developing nations. Table 2 below summaries key infrastructure challenges, instances, and their impacts on EV adoption:

**Table 2.** Key challenges in electric vehicle adoption across developing countries.

| **Challenge** | **Examples** | **Impact** |
|---|---|---|
| Limited Charging Infrastructure [26] | Nigeria, Bangladesh | Inadequate public charging stations restrict EV usability and convenience. |
| Unreliable Power Grids [11] | India, South Africa | Frequent power outages undermine charging reliability and consumer trust. |
| Urban-Rural Disparity [20,22] | Indonesia, Kenya | Charging infrastructure is concentrated in urban areas, excluding rural users. |
| Grid Capacity Constraints [27] | Pakistan, Vietnam | Overburdened grids are unable to support widespread EV adoption. |

| | | |
|---|---|---|
| High Infrastructure Costs [28] | Philippines, Ghana | Lack of funding delays the deployment of essential charging networks. |
| Technology Gaps [29] | Uganda, Cambodia | Limited access to advanced charging technologies hinders adoption speed. |

**Policy frameworks and regulatory gaps**

Policy frameworks and regulatory gaps significantly influence the adoption of EVs in developing countries. While developed nations like Norway and China have implemented robust policies, including subsidies, tax incentives, and zero-emission mandates, developing regions often lack cohesive strategies tailored to their specific challenges. This absence of a structured policy environment hinders private-sector investment and limits consumer adoption. The policy barriers to EV adoption in developing nations are presented in Table 3. EVs are beyond range for lower-income groups in Bangladesh and India because of a lack of monetary incentives. Customers and manufacturers in South Africa and Brazil remain hesitant amid scattered policies. In countries like India, dependence on coal reduces the environmental advantages associated with EVs. Infrastructure development in Vietnam and Nigeria is being slowed down because of a lack of collaboration between the public and private sectors. In Southern Asia and Sub-Saharan Africa, inefficient national strategies have failed to create trust and bring in investors. In African and Southeast Asian nations, a disproportionate reliance on imported EV technology increases costs. In Latin America, inadequate planning for cities leads to charging infrastructure bottlenecks. South Asian and Brazilian deferred regulations regarding emissions have impeded EV adoption. In South Asia and Indonesia, insufficient access to transportation systems limits the use of EVs in public transportation, reducing their impact.

**Table 3.** Policy barriers to EV adoption: examples and impacts in developing countries.

| **Policy Barrier** | **Example** | **Impact** |
|---|---|---|
| Lack of financial incentives and affordable financing options [30] | India, Bangladesh | High upfront costs of EVs remain unaffordable for lower-income groups, limiting adoption. |
| Fragmented regulations and inconsistent policies [31] | Brazil, South Africa | Inconsistent EV adoption strategies create market uncertainty for manufacturers and buyers. |
| Absence of long-term renewable energy strategies [32] | Coal-dependent countries like India | The environmental benefits of EVs are diminished due to reliance on coal for electricity. |
| Limited public-private partnerships [33] | Nigeria, Vietnam | Insufficient infrastructure growth, including EV charging networks, hinders adoption. |
| Weak national EV strategies [34] | Sub-Saharan Africa, South Asia | Failure to attract private-sector investment and build consumer confidence. |
| Over-reliance on imported EV technology [35] | African nations, Southeast Asia | Local industries lack growth opportunities, increasing dependency and costs. |
| Lack of EV-specific urban planning [36] | Latin America | Charging infrastructure fails to meet urban demand, leading to adoption bottlenecks. |

 doi:10.20944/preprints202501.2083.v1



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|---|---|---|
| Delayed implementation of emission mandates [37] | Brazil, South Asia | Slow regulatory changes reduce the urgency for manufacturers to shift to EV production. |
| Weak integration with public transport systems [38] | South Asia, Indonesia | EV adoption fails to address mass transit challenges, limiting environmental benefits. |

**Market potential and key barriers in developing countries**

The market potential for electric vehicles (EVs) in developing countries is significant, driven by rising urbanization, increasing environmental awareness, and a growing middle class. Nations such as India, Brazil, and South Africa are witnessing an uptick in demand for affordable and sustainable transportation solutions, offering promising opportunities for EV market growth. However, this potential is hindered by several key barriers that limit widespread adoption. Table 4 covers the primary challenges to EV adoption in developing countries in addition to the market potential. The demand for sustainable and affordable transportation grows in South Africa and India as a consequence of increasing urbanization. The prospective market for EVs grows with the expanding middle classes in Brazil and Indonesia. Price-sensitive markets consider it challenging to manage the high upfront costs in Nigeria and Bangladesh. In Southeast Asia and Africa, dependence on imports increases the cost of EVs and limits their accessibility. Lower-income people in Brazil and Vietnam are neglected mainly because of a lack of financing alternatives. The use of electric vehicles is limited in semi-urban and rural regions in Kenya and Pakistan simply because of inadequate charging infrastructure. The deployment of charging infrastructure faces obstacles from South Africa and India's unstable power grids. In Sub-Saharan Africa, the urban-rural divide restricts the adoption of EVs in rural areas. In Bangladesh and Brazil, policy and regulatory gaps prevent investment and diminish customer confidence.

**Table 4.** Market potential and key barriers to EV adoption in developing countries.

| **Aspect** | **Example** | **Impact** |
|---|---|---|
| Rising urbanization and environmental awareness [39] | India, South Africa | Increased demand for affordable and sustainable transportation solutions drives EV market growth. |
| Growing middle class [40] | Brazil, Indonesia | Expanding middle-income populations provide a larger consumer base for EV adoption. |
| High upfront costs of Evs [41] | Bangladesh, Nigeria | Price-sensitive markets face reduced affordability, limiting ownership to higher-income groups. |
| Dependence on imports [35] | African nations, Southeast Asia | Lack of local manufacturing raises EV prices and restricts access in cost-sensitive regions. |
| Limited financing options [30,42] | Brazil, Vietnam | The absence of affordable financing leaves lower-income populations underserved. |
| Inadequate charging infrastructure [43] | Kenya, Pakistan | Insufficient charging networks restrict EV usage, particularly in rural and semi-urban areas. |
| Unreliable power grids [27] | South Africa, India | Frequent power outages reduce consumer trust and hinder charging network development. |
| Urban-rural disparity [20,22] | Indonesia, Sub-Saharan Africa | Rural areas lack basic electricity and charging infrastructure, limiting EV adoption outside cities. |

| | | |
|---|---|---|
| Policy and regulatory gaps [44] | Brazil, Bangladesh | Weak incentives and inconsistent policies fail to attract investments and build consumer confidence. |

According to the Tesla website (Tesla.com), 10 million EVs were sold globally in 2022, indicating the meteoric rise of EV adoption triggered by favorable regulations, technology improvements, and increasing environmental awareness. Yet, unique challenges that limit accessibility and consumer confidence are encountered in developing countries, such as a lack of infrastructure, unreliable power grids, and high upfront costs. The adoption of electric vehicles is further hindered because of the lack of cohesive policy frameworks and public-private partnerships, especially in semi-urban and rural regions. This study aims to fill these gaps through highlighting significant problems and proposing specific solutions like improving charging infrastructure, promoting affordable EV models, and advocating modifications to laws that encourage equitable and long-term EV adoption in developing countries. To do so, a case study is conducted to examine the possible scenarios when they transform their transportation fleet into partial hybrids and EV adoptions to observe the favorable parameter changes using simulation modeling.

## Research Methodology

### Research Design

This study adopts a mixed-method integrating system dynamics modeling and case study to discover the transportation-related challenges and prospects in light of Bangladeshi livestock farms operating 142 vehicles of various types. Bangladesh is one of the perfect countries to consider for research as it is now the 35th largest economy (https://bida.gov.bd), though it has been known as a poor and densely populated region for a long. Bangladesh has progressed significantly in terms of roads and highways, livestock, garments, consumer goods, and many other sectors like steel, cotton, glass, cars, and appliances. The case industry uses its 142 vehicles to carry typical products like Chicken, Day-old Chicks, poultry and dairy feed, milk, milk-related value-added products like yogurt, pasteurized milk, and flavored drinks, and horticulture products like fruits, vegetables, paddy, corn, etc. This study only considers products carrying and 21 private vehicles used in internal project areas and for higher executives to commute from one unit to another unit for inspections. This research also assesses Diesel, Octane, and Compressed Natural Gas (CNG) used vehicles. An average is calculated per mile to avoid the complexity of different modes of gasoline usage in different vehicles. The research mainly focuses on understanding the future transformation of EVs or hybrid vehicles to hypothetically analyze the economic, operational, and infrastructural benefits and challenges. The design incorporates:

I. System Dynamics (SD) Approach: The paper deployed the SD simulation model and simulated the interconnected variables to observe transitioning to Hybrids and EVs and find possible changes in operational costs, carbon emissions, and efficiency.

II. Case Study Approach: A case Bangladeshi livestock farm considers drawing a simulation model and replicating its current processes. Later, hypothetical values are considered input to understand future transformations in light of key indicators. The case industry is one of the largest farms in terms of producing and transporting day-old chicks, milk, and livestock feed production and marketing of their products all over Bangladesh. Bangladesh is a small country of approximately 95,000 square miles, and the case farm's vehicle moves more than 5,50,000 miles per month.

The Mixed method helps design the model through a qualitative and quantitative understanding of the transportation networks. Such design confirms a comprehensive understanding of theoretical modeling and practical implications, which will bridge the gap between systematic investigations and industry realities.

**System Dynamics Simulation Model Development**

The SD model is developed to simulate the transportation dynamics based on mileage traveled in one month using their vehicles. The paper used the Vensim 6.01b application to draw a simulation model, replicating the current process and scenario analyses using hypothetical data. This model accumulated data from 142 vehicles that operate for commercial, private, milk transport, and egg transport vehicles. Key variables incorporated into the model include:

I. Fleet Composition: The type and number of vehicles. The model simplified the categories into Private Vehicles and Product-Carrying Vehicles.
II. Fuel Consumption: Differentiating between Diesel, Octane, and CNG fuel sources.
III. Fuel Costs: The total fuel costs combined make an average per-mile cost.
IV. Operational Metrics: Operational metrics rely on vehicle mileage (Bangladesh measures in kilometers but converted to miles for modeling purposes), maintenance costs (repairs, spare parts), fuel costs, and consumption efficiency.
V. Carbon Emissions: Most vehicles use diesel, and only 20 percent use Octane and CNG. The study estimates carbon emissions based on average mileage and fuel consumption. The average is nearly 1.46 Kg of carbon emissions while driving one mile by a 5-ton semi-truck.

The model integrates feedback loops, such as cost versus profit and wear-and-tear impacts on vehicle availability, to provide dynamic insights into the system.

**Data Collection**

This study collected primary and secondary data to ensure thorough coverage of transportation information from the case industry and general information. The transportation logbook from the case livestock industry and their supply chain operations all over the country provided the primary data. This farm operates more than 200 vehicles of different kinds, but its records show 142 vehicles operated primarily for carrying products from various destinations. The study kept 21 vehicles from private usage, maintaining records for high mobility. The study did not include the rest of the vehicles due to a lack of mobilities and logbook records, as these vehicles run within particular projects for internal movement. For example, every project is 25 to 50 acres of land, and they need internal vehicles for stuff and feed and other ingredients movements internally. They use some golf carts that are battery-operated and environmentally friendly. Through in-depth, open-ended interviews with the logistics manager and fleet operators, key operational information was collected, including miles, consumption of fuel, repair costs, vehicle utilization rates, etc. The study extracts scholarly research papers from journals, periodicals, and reputed websites for theoretical support. For example, standard carbon emission per mile was extracted from literature and EV manufacturing vehicle websites and crosschecked among different sources.

**Case Farm Selection**

The case study methods deployed to justify the study consider the developing country's environment. This research purposively chose large-scale single livestock farms for their scale of operations and diverse fleet operations. This farm has the largest dairy in Bangladesh and is among the top few companies considering day-old chick production and marketing in the country. They produce 10 million chicks per month and distribute them to more than two thousand small-medium poultry farmers all over Bangladesh through 15 different zonal offices and 150 agents. They also produce 40,000 tons of livestock feed for commercial and internal consumption. They have their own Grant Stock (GP) and Parent Stock (PS) farms, where they hatch ten million chicks at a hatching capacity in a month. This farm is one of the few that represents typical transportation challenges facing constantly dealing with supply chain complexities. They also maintain their logbook for authentic information for managerial decisions, Tax, and Value Addition Taxes (VAT) purposes. Their transportation operations highlight air and noise pollution, cost inefficiencies, fossil fuel dependence, seasonal fluctuations, frequent accidental expenses, and unexpected maintenance costs. Their urban and rural coverage is also helpful in understanding the limitations of charging infrastructure and consistent electricity supplies, making it an ideal topic for studying EV adoption in the livestock supply chain.

## Simulation Model on a Case Industry Transportation Fleet

### Mental Model

In order to thoroughly understand the complicated transportation processes, cost factors, and revenue generation associated with fleet management, in-depth interviews with managers, operators, and staff involved in transport logistics were carried out to develop the mental model. According to insights acquired through these interviews, important variables such as gasoline usage, maintenance costs, driver costs, and income sources are interrelated. Respondents highlighted the impact of fleet composition decisions, including the adoption of EVs and hybrids, upon reducing expenses and efficiency in operation. Furthermore, governmental fees, tolls, and greenhouse gases have been addressed in addition to techniques for maximizing fuel efficiency and mileage. The mental model provides a comprehensive structure to assess the functional, economic, and ecological impacts of transitioning to sustainable automotive technologies in fleet management using stakeholders' operational expertise and actual life experience. This collaborative approach ensures that the framework is an effective instrument for policy formulation and choice-making and precisely reflects the actual state of fleet management.

### Monthly Transportation Costs

For a fleet of 142 vehicles, Table 5 illustrates the monthly transportation expenses for each subsequent category: Chicks, Feed, Commercial, Private, Milk, Egg, and Project transport types. It shows data regarding total miles driven, repair costs, tolls, driver wages, costs of gasoline, and taxes. Chicks' carrying transportation costs were the highest, traveling 269,057 miles and leading to heavy fuel (4,098,678), maintenance (793,373), and driver pay (746,418) expenses. On the other hand, the Project classification has the lowest expenses and the least mileage (9,069). The mean price per mile is determined, and the total expenditures for all categories are displayed at the end of the table. Fuel costs 16.83, repair expenses 4.01, tolls expenses 2.09, driver wages and food costs 2.75, and Government tax costs 0.64. The operational necessities, along with the expense allocation of the various vehicle types in the transportation fleet, are emphasized through this information. All the calculations are converted in light of per mile traveling of a vehicle and calculated in Bangladeshi currency of Taka (BDT). Later, the simulation model converted all the values into BDT to US dollars.

**Table 5.** Monthly transportation expenses.

| Sl No | Vehicle | Total | Miles | Fuel Costs | Maintenance | Toll Fee | Driver | Tax |
|---|---|---|---|---|---|---|---|---|
| 1 | Chicks | 51 | 269,057 | 4,098,678 | 793,373 | 473,019 | 746,418 | 77,274 |
| 2 | Feed | 24 | 71,930 | 1,511,757 | 419,032 | 67,650 | 208,408 | 25,579 |
| 3 | Comercial | 14 | 73,894 | 1,567,678 | 212,198 | 296,635 | 228,002 | 11,550 |
| 4 | Private | 21 | 28,546 | 300,882 | 182,025 | 6,260 | 15,790 | 51,820 |
| 5 | Milk | 8 | 14,624 | 235,515 | 119,220 | 600 | 33,848 | 24,078 |
| 6 | Egg | 10 | 54,963 | 971,999 | 306,599 | 246,949 | 197,409 | 35,142 |
| 7 | Project | 14 | 9,069 | 101,037 | 62,643 | 1,630 | 4,583 | 10,500 |
| Total | | 142 | 522,083 | 8,787,546 | 2,095,090 | 1,092,743 | 1,434,458 | 335,943 |
| Average Expenses per Mile | | | | 16.83 | 4.01 | 2.09 | 2.75 | 0.64 |

### Transportation Fleet Simulation Model

Figure 1 provides an inclusive system dynamics model for analyzing the economic, environmental, and operational impacts of vehicle adoption and fleet management, mainly focusing on hybrid and electric vehicle (EV) integration. While addressing their interdependencies, the model encompasses key variables, including carbon emissions, total mileage, operational costs, and revenues. It highlights factors like fuel consumption, maintenance, government taxes, and driver costs, offering a framework for evaluating the transition to sustainable transportation options in a fleet management system.

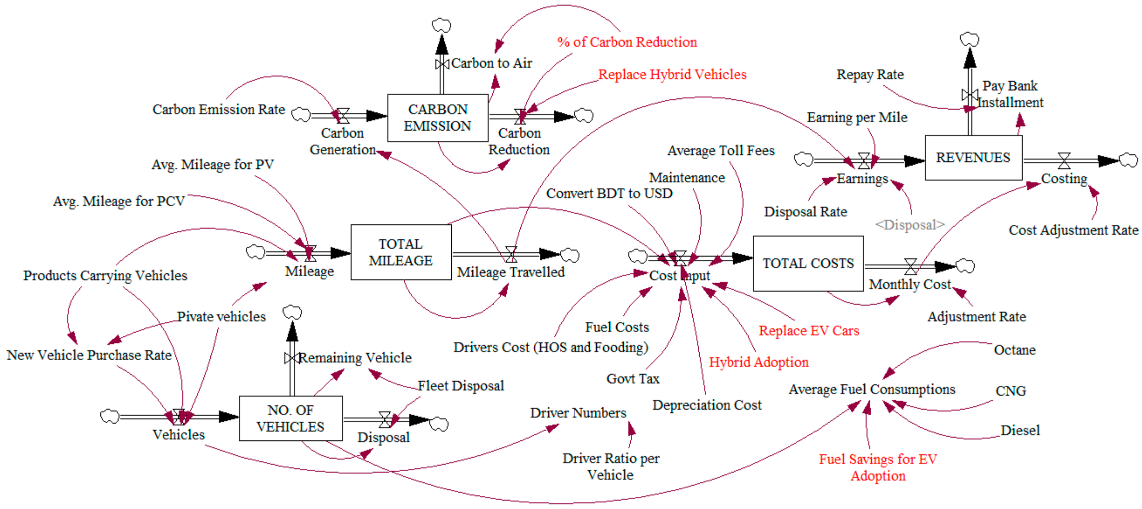


**Figure 1.** Simulation Model on Transport Fleet of a Case Industry.

The model's core components include Carbon Emissions, Total Costs, and Revenues, with feedback loops capturing the impact of variables like mileage, vehicle types, and fuel consumption. For instance, carbon emissions are affected by the total mileage and the adoption of hybrid and EV technologies, which contribute to carbon reduction. Similarly, total costs are influenced by vehicle maintenance, fuel consumption (CNG, diesel, and octane), and toll fees, with potential cost savings achieved through EV adoption. Revenues are determined by operational efficiency, earnings per mile, and cost adjustments. This model serves as a decision-making tool, enabling stakeholders to evaluate the economic feasibility and environmental benefits of transitioning to hybrid and EV fleets. Simulating the effects of replacing fossil-fuel-powered vehicles with sustainable alternatives provides insights into potential cost savings, carbon reduction, and the long-term sustainability of fleet operations. This approach is particularly relevant for industries seeking to balance profitability with environmental responsibility.

The stock variables below are the main factors to compare among vehicle choices.

**No. of Vehicles**

- Represents the total fleet size, which impacts overall transportation operations.
- Directly connected to Fleet Disposal (removal of older vehicles) and New Vehicle Purchase Rate, affecting the fleet composition.
- Influences Total Mileage, as more vehicles lead to higher cumulative distance covered.
- The fleet size determines Driver Numbers and Driver Ratio per Vehicle, contributing to labor costs.
- Transition to hybrid or EV vehicles (via Replace Hybrid Vehicles and Replace EV Cars) reshapes the fleet for sustainability.

**Total Mileage**

- Represents the cumulative distance covered by the fleet.
- Affected by the type of vehicles, with separate considerations for Avg. Mileage for PV (Private Vehicles) and Avg. Mileage for PCV (Product-Carrying Vehicles).
- Directly influences Fuel Costs, Maintenance, and Toll Fees, which feed into Total Costs.
- Higher mileage from fossil-fuel vehicles increases Carbon emissions, while hybrid and EV adoption reduces the emission rate.

- Drives Revenues, as mileage is a key factor in calculating earnings per mile.

**Total Costs**

- Captures all expenses, including Fuel Costs, Maintenance, Toll Fees, Driver Costs, and Govt Tax.
- Influenced by Fleet Disposal (older vehicles are more expensive to maintain) and the adoption of Hybrid Vehicles and EV Cars, which reduce fuel and maintenance expenses.
- Higher mileage increases costs, particularly for fossil-fuel vehicles, but fuel savings from EV adoption mitigate these impacts.
- Directly affects Revenues, as cost adjustments can improve profit margins.
- Connected to Cost Adjustment Rate, allowing for operational efficiency evaluation.

**Revenues**

- Represents income generated from fleet operations, determined by Earning per Mile and total mileage.
- Dependent on operational efficiency, as higher Total Costs reduce profit margins.
- Influenced by the repayment rate, which reflects installment payments for new vehicles, including hybrids and EVs.
- Disposal Rate contributes to revenues through the sale of decommissioned vehicles.
- A strong focus on sustainability (via hybrid and EV adoption) increases long-term profitability by reducing operational costs and carbon penalties.

**Carbon Emission**

- It reflects total greenhouse gas emissions from the fleet, which are influenced by the carbon emission rate and total mileage.
- High emissions are driven by fossil-fuel vehicles, while Hybrid Vehicles and EV Cars significantly reduce carbon output.
- Connected to the percentage of carbon reduction, which tracks the environmental impact of adopting sustainable technologies.
- Carbon reduction strategies influence policy compliance and operational reputation, indirectly affecting Revenues.
- Long-term reductions in emissions align with lower fuel consumption and maintenance costs, as seen in the Total Costs variable.

## Findings and Discussion

### Simulated Results for Current Scenario vs. Hybrid and EV Adoption

The simulation results reveal notable distinctions between the current transportation model and adopting Hybrid and EVs. The findings across key variables strongly support transitioning to hybrid and EV technologies to enhance operational efficiency, reduce costs, and align with sustainability goals. However, as there is no evidence of EVs being available for 5-ton trucks, it is not easy to assess their feasibility. Thus, hybrid vehicles emerge as the better option.

**I. Carbon Emissions:**

The current system generates significant carbon emissions, primarily driven by fossil-fuel-based vehicles. High mileage and inefficient fuel consumption further contribute to an unsustainable environmental footprint. In the hybrid and EV adoption scenario, carbon emissions are drastically reduced due to the energy efficiency of hybrid vehicles and the zero-emission nature of EVs. Figure 2 compares carbon emissions under the current process (red line) with the "Hybrid and EV adoption" scenario (blue line) over 60 months. Hybrid and EV adoption significantly reduces carbon emissions, showcasing the environmental benefits of transitioning from fossil-fuel-based systems to sustainable

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vehicle technologies. This demonstrates the financial viability of transitioning to hybrid and EV technologies. The simulation highlights a substantial carbon reduction percentage, showing the environmental benefits of transitioning to cleaner vehicle technologies. Reducing carbon emissions enhances environmental sustainability and aligns with global climate goals, improving the organization's reputation and compliance with regulatory standards.

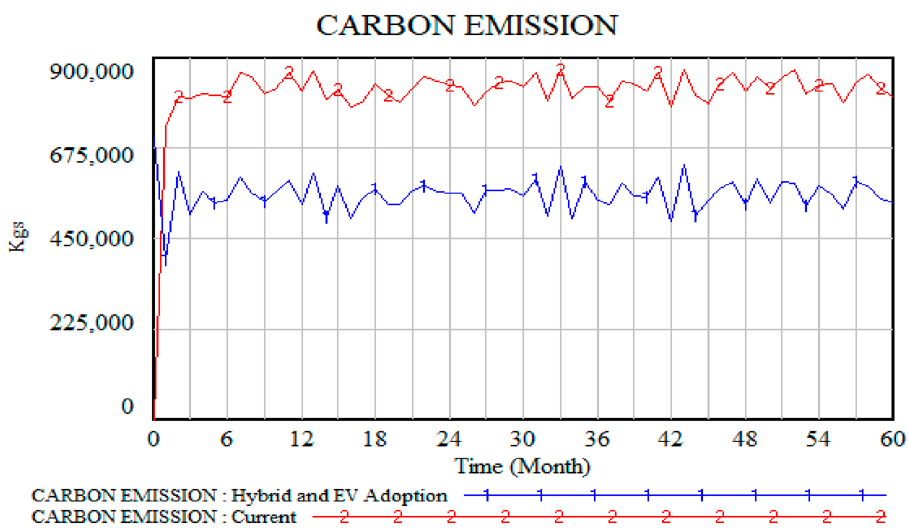


**Figure 2.** Simulated Results of carbon Emission in five years for both scenarios.

**II. Total Costs**

Operational costs are high in the current scenario due to significant spending on fuel, frequent maintenance of older vehicles, and toll fees. Rising fuel prices further exacerbate the cost inefficiencies of the current system. Figure 3 shows the total costs under the current process (red line) and the hybrid and EV adoption scenario (blue line) over 60 months. In the hybrid and EV adoption scenario, costs remain consistently lower, reducing from approximately $95,000 in the current system to around $67,000, reflecting significant savings in fuel consumption and maintenance expenses. This demonstrates the financial viability of transitioning to hybrid and EV technologies. In the hybrid and EV adoption scenario, total costs decrease significantly, primarily driven by lower fuel consumption, reduced maintenance requirements for EVs, and energy savings. While there is an initial investment in vehicle replacement, the long-term financial benefits outweigh these costs. Hybrid vehicles, in particular, provide a feasible and cost-effective solution for reducing operational costs.

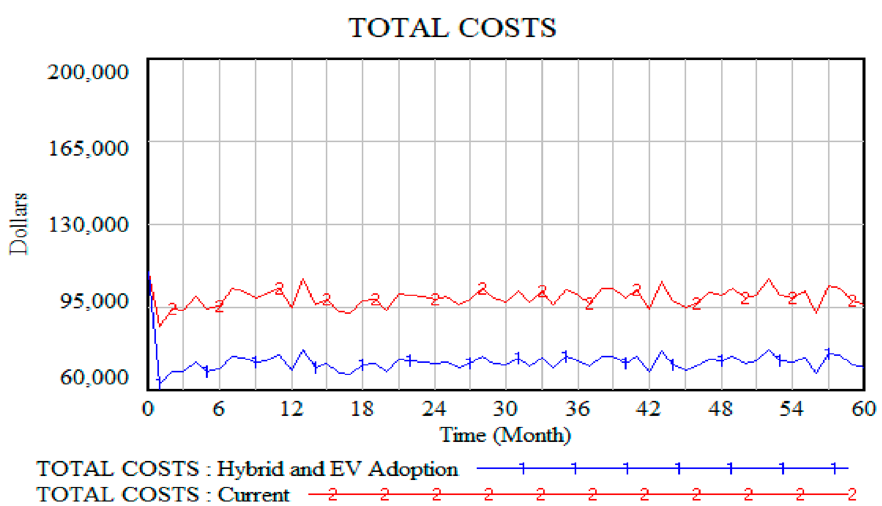


**Figure 3.** Simulated Results of 'Total Costs' in five years for both scenarios.

**III. Total Mileage and Fuel Savings**

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The fleet generates substantial mileage using fossil-fuel vehicles, leading to higher carbon emissions and fuel expenses. The operational inefficiencies of older vehicle technologies exacerbate these challenges. Figure 4 demonstrates the average fuel consumption under the current process (red line) and the 'Hybrid and EV adoption' scenario (blue line) over 60 months. The hybrid and EV adoption scenario significantly reduces fuel consumption, consistently maintaining levels around $37,000 compared to the current process, which averages approximately $91,000. This highlights the fuel efficiency and cost-saving potential of transitioning to hybrid and electric vehicle technologies. Total mileage remains constant in the hybrid and EV adoption scenario, but the environmental and financial impact per mile is significantly reduced. Hybrid and EVs demonstrate better mileage efficiency and optimized energy use, improving overall operational efficiency. Transitioning to hybrid and EVs enhances energy efficiency and maximizes the operational output of mileage, reducing environmental and economic strain.

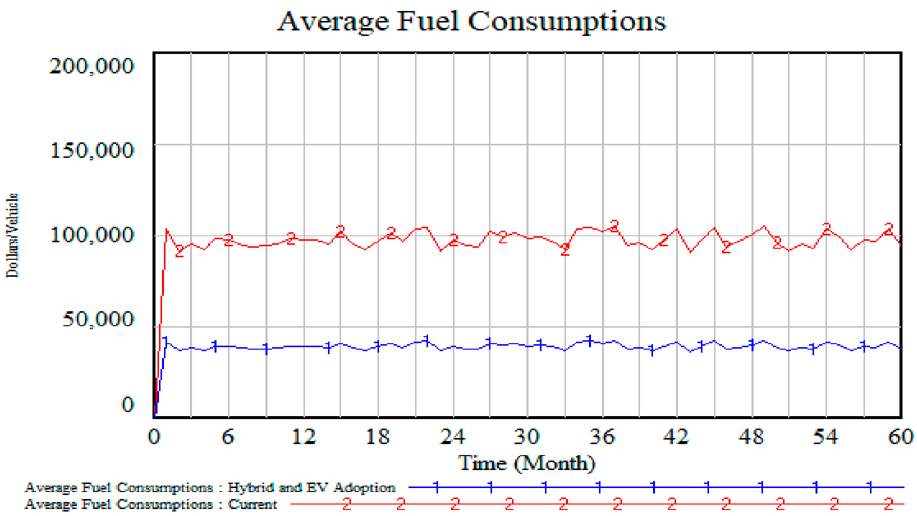


**Figure 4.** Simulated Results of 'Average Fuel Consumptions' for both scenarios.

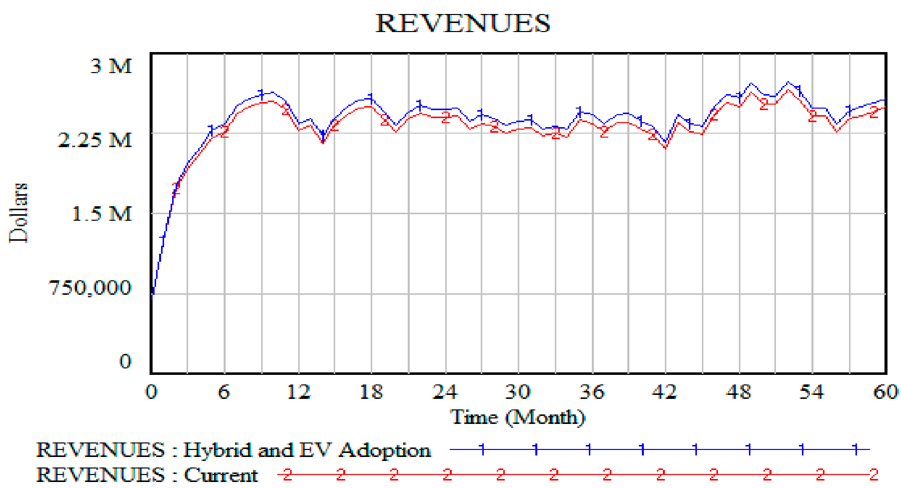


**Figure 5.** Simulated Results of 'Revenues' in five years for both scenarios.

**IV. Revenues**

Revenues in the current scenario are limited by high operational costs, which reduce profitability despite steady earnings per mile. The graph compares revenues under the current process (red line) and the hybrid and EV adoption scenario (blue line) over 60 months. The hybrid and EV adoption scenario consistently generates higher revenues, reaching approximately $2.6 million compared to $2.5 million in the current process. The upfront costs are absorbing additional revenues from the EV-transformed scenarios; otherwise, the revenues will look much greater than this. This reflects improved profitability due to reduced operational costs and enhanced efficiency with hybrid and EV technologies. The economic inefficiencies of fossil-fuel-based fleets hinder long-term growth potential. In the hybrid and EV adoption scenario, increased profitability is achieved due to reduced operational costs. Lower fuel expenses, minimal maintenance, and the improved reliability of hybrid and EVs enable better financial performance. Additionally, compliance with environmental regulations avoids potential fines, further supporting revenue growth. Hybrid vehicles, being more readily available for larger trucks, offer a reliable way to boost revenues while transitioning to sustainable practices.

**V. Fleet Size and Composition**

The current fleet comprises fossil-fuel-powered vehicles with varying energy efficiencies and high maintenance needs. Fleet disposal and replacement are infrequent, leading to operational inefficiencies. The hybrid and EV adoption scenario modernizes the fleet with cleaner technologies, reducing fuel dependency and improving overall efficiency. Transitioning to hybrid vehicles is particularly practical given the lack of EV availability for 5-ton trucks, ensuring cost efficiency and reliability while supporting sustainability initiatives. The simulated results clearly demonstrate that adopting hybrid and EV technologies offers substantial benefits over the current fossil-fuel-based system. Key variables such as carbon emissions, total costs, revenues, and operational efficiency show marked improvements, making the transition an economically and environmentally sound decision. However, due to the lack of evidence for the feasibility of EVs for 5-ton trucks, hybrid vehicles are the better immediate option. They provide a balanced solution by reducing operational costs, improving sustainability, and ensuring the reliability of transportation operations. Hybrid adoption ensures long-term efficiency while paving the way for the gradual integration of EVs as their technology advances.

Table 6 compares the key variables of two scenarios—current operations and hybrid/EV adoption over 60 months. In the hybrid/EV scenario, average fuel consumption drops significantly, from 39,092 liters in month 5 to 37,530 liters in month 60, compared to the consistently higher consumption in the current scenario. Carbon emissions also reduce drastically, with 537,967 kg in month 5 under the hybrid/EV scenario versus 807,196 kg in the current scenario, showcasing substantial carbon reduction over time. Revenues are higher in the hybrid/EV scenario, reaching 2.578 million USD in month 60 compared to 2.498 million USD in the current scenario. Total costs in the hybrid/EV model are consistently lower, demonstrating cost efficiency through reduced fuel and maintenance expenditures. The number of vehicles and total mileage remains constant across both scenarios, highlighting the operational scale's stability while improving sustainability and profitability through hybrid/EV adoption. This comparison underscores the economic and environmental benefits of transitioning to hybrid and EV technology.

**Table 6.** Results for key variables for two different Scenarios.

| Time (Month) | 5 | 15 | 25 | 35 | 50 | 60 |
|---|---|---|---|---|---|---|
| Avg. Fuel Consumptions* | 39,092 | 40,625 | 37,764 | 41,814 | 38,461 | 37,530 |
| : Current Scenario | 97,731 | 101,563 | 94,409 | 104,534 | 96,152 | 93,824 |
| CARBON EMISSION* | 537,967 | 581,165 | 561,604 | 590,365 | 538,282 | 539,897 |
| : Current Scenario | 807,196 | 820,705 | 829,166 | 828,051 | 822,986 | 801,019 |
| Carbon Reduction* | 94,144 | 101,704 | 98,281 | 103,314 | 94,199 | 94,482 |
| : Current Scenario | 807,196 | 820,705 | 829,166 | 828,051 | 822,986 | 801,019 |
| NO. OF VEHICLES* | 149.2 | 149.38 | 150.67 | 151.42 | 150.4 | 150.06 |
| : Current Scenario | 149.2 | 149.38 | 150.67 | 151.42 | 150.4 | 150.06 |
| REVENUES* | 2.272 M | 2.395 M | 2.484 M | 2.445 M | 2.608 M | 2.578 M |
| : Current Scenario | 2.208 M | 2.321 M | 2.410 M | 2.371 M | 2.528 M | 2.498 M |
| TOTAL COSTS* | 67,914 | 71,108 | 71,671 | 73,929 | 71,300 | 69,322 |

| | | | | | | |
|---|---|---|---|---|---|---|
| : Current Scenario | 93,999 | 98,419 | 99,198 | 102,324 | 98,685 | 95,947 |
| TOTAL MILEAGE* | 548,896 | 531,885 | 534,216 | 565,995 | 580,274 | 543,548 |
| : Current Scenario | 548,896 | 531,885 | 534,216 | 565,995 | 580,274 | 543,548 |
| *Hybrid/EV adoption scenarios | | | | | | |

The above investigation of the operational, financial, and ecological implications of converting to hybrid and EVs is feasible using the transportation fleet simulation framework developed for the case industry. According to the investigation, adopting EV and hybrid technologies offers multiple benefits, such as lower operating costs, higher revenues, and decreased carbon emissions. The simulation demonstrates how environmentally friendly fleet management strategies may enhance overall efficiency and profitability by including important variables like gasoline use, maintenance, carbon emissions, and revenue generation. The absence of EVs for larger trucks makes hybrids the most feasible option at the moment; however, they additionally provide an equitable approach to reduce reliance on fossil fuels and integrate operations with environmental goals. The company intends to accomplish financial and ecological advantages for the transportation sectors for a long time; this evaluation highlights the importance of specific investments in infrastructure, fleet modernization, and government support. The findings indicate that effectively embracing hybrid vehicles ensures cost savings and operation reliability while providing a foundation for the future integration of electric cars as technology advances.

**Emerging Opportunities for EV Markets in Developing Nations**

Based on the above analyses from the transport fleet model from a case industry, the paper listed several emerging opportunities for the EV market in developing nations, which are as follows:

I. Emerging EV Markets in Developing Nations: Any developing nation with a growing middle-class population is becoming a potential EV market due to rapid urbanization, which raises environmental awareness. For instance, India, Brazil, South Africa, and Bangladesh are countries with growing populations along with moderate education, infrastructural developments, and technological learning and facilities. These factors create opportunities for EV growth, especially in urban and semi-urban regions.

II. Barriers to EV Adoption: Despite the promising potential, EV adoption in developing nations remains low due to economic constraints, limited infrastructure, and policy gaps. High upfront costs, inadequate charging infrastructure, and unreliable electricity are common challenges faced in countries like India and Nigeria.

III. Urban-Centric Market Trends: The EV market in countries like Brazil is largely concentrated in urban centers, with rural areas having limited access. Similarly, India has seen growth in electric two-wheelers and three-wheelers, but the electric car and bus markets remain underdeveloped due to affordability and infrastructure limitations.

IV. Dependence on Imported EV Models: Many developing nations rely heavily on imported EV models, driving up costs and limiting accessibility for middle- and lower-income groups. The lack of local manufacturing prevents economies of scale, making EVs less competitive and widely affordable.

V. Progress Through Localized Initiatives: Some countries are making strides through innovative approaches. Kenya has seen growth in electric motorcycles driven by rising fuel costs and local startup support, while Indonesia is leveraging its nickel reserves to attract EV battery manufacturers and promote localized production.

VI. Need for Targeted Policies and Investments: Developing nations must adopt targeted strategies, including promoting affordable EV models, expanding charging infrastructure, and creating incentives. These measures can help address barriers and leverage the growth potential of EV markets across diverse regions and demographics.

**Recommendations for Tailoring Global Practices to Local Contexts**

The above discussions and results were communicated with the industry representatives to verify possible recommendations for local perspectives. Every country is unique in terms of infrastructure, perceptions, capability, and governance. The study finds some useful recommendations for local perspectives based on global practices on EVs.

I. Promote Affordable EV Models: To cater to price-sensitive consumers, governments must prioritize producing and promoting affordable EV models such as two-wheelers, three-wheelers, and small electric cars. India's focus on electric scooters and auto-rickshaws is a successful example of targeting affordability and accessibility, making EVs more viable for the general population.

II. Develop Scalable Charging Infrastructure: Establishing cost-effective and scalable charging infrastructure is essential for widespread EV adoption. Leveraging solar-powered charging stations can address electricity reliability issues while simultaneously integrating renewable energy into the EV ecosystem, reducing reliance on conventional energy sources.

III. Implement Tailored Policy Incentives: Clear and consistent policy frameworks, such as subsidies for manufacturers, reduced taxes on EV imports, and concessional financing for buyers, are crucial for lowering barriers to EV adoption. Additionally, region-specific policies should focus on rural electrification and underserved areas to ensure equitable access to EV technology.

IV. Encourage Public-Private Partnerships: Governments should collaborate with private firms to accelerate charging networks and Infrastructure deployment. As demonstrated in the United States, public-private partnerships can ensure widespread coverage, leveraging private sector expertise and investment to create a sustainable EV ecosystem.

V. Foster International Collaborations: Partnerships with global automakers and battery manufacturers can facilitate technology transfer and reduce production costs. Developing nations should also seek funding from international bodies to support EV initiatives, accelerate local production, and build a robust and sustainable transportation network.

**Policy Recommendations**

The paper also provides short-term, medium-term, and long-term policy recommendations, as none of the developing nations can fully transform from conventional to EV. The transformation is expensive and requires additional costly infrastructure and customers' positive perceptions of EV technology.

I. Short-term policy on introducing incentives and pilot infrastructure projects: In the immediate term, governments in developing countries should focus on creating financial incentives to make EVs more affordable. Subsidies for EV buyers, tax reductions, and concessional financing options can significantly lower the barriers to entry for consumers. Pilot projects to build localized charging infrastructure in urban centers can also serve as test cases for larger-scale implementation. Public-private partnerships can accelerate these projects, ensuring cost-effective solutions and quick deployment. For example, subsidized solar-powered charging stations could address both affordability and energy reliability issues.

II. Medium-term on developing nationwide infrastructure and fostering partnerships: The focus should shift toward expanding EV infrastructure nationwide over the medium term. Developing a comprehensive charging station network, particularly in underserved rural areas, is critical to promoting widespread adoption. Governments must partner with private firms and

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international organizations to secure the necessary funding and technical expertise. India's FAME (Faster Adoption and Manufacturing of Electric Vehicles) initiative serves as a valuable model, combining infrastructure development with policy support. Furthermore, standardizing EV regulations across regions will reduce uncertainty for manufacturers and investors, encouraging them to participate in the market.

III. Long-term policies on building renewable-integrated EV ecosystems and robust regulatory frameworks: In the long term, integrating renewable energy into EV ecosystems is essential to maximize their environmental benefits. Investments in renewable energy sources, such as solar and wind, should be prioritized to power EV charging networks sustainably. Robust regulatory frameworks must be established to ensure long-term market stability and innovation. Policies that promote domestic EV manufacturing can reduce reliance on imports, lowering costs and boosting local economies. International collaborations can further support the development of technology and infrastructure tailored to the needs of developing nations.

## Conclusions

The study underlines the potential of electric vehicles as a sustainable transportation solution for developing countries and also identifies considerable adoption hurdles. Major issues include poor infrastructure, hefty upfront expenses, and fragmented policy frameworks. The investigation highlights localized approaches geared to emerging nations' socio-economic and infrastructure realities. The case study scenarios analyses of the system dynamics simulation models also demonstrated better outcomes in inducing carbon emission and transportation expenditures through EV adaptation. At the same time, the initial investment goes high along with country and company infrastructures. The repair cost and location are other issues to solve before they go for EVs. Affordable EV vehicles, scalable charging solutions, and targeted financial incentives are needed to close these gaps. The focus on electric two- and three-wheelers in Bangladesh shows the usefulness of creating tactics to meet local needs. By adopting these personalized solutions, developing nations may reap the benefits of EVs, including lower emissions, energy security, and economic growth. Governments, industry, and international organizations must collaborate on EV transformation for global and country causes. Worldwide knowledge and funding are needed to speed infrastructure and technology transfer in developing nations. UN and World Bank partnerships can provide finance and technical expertise for significant projects. Collaborations with major automakers and renewable energy sources can reduce costs and innovate. Creating egalitarian and sustainable EV ecosystems that solve local and global issues requires international cooperation.

Future studies should examine how cultural norms and consumer behavior affect EV adoption in underdeveloped nations. Social acceptance, environmental awareness, and attitudes toward new technology vary by area and influence market demand. Research should integrate renewable energy sources into EV charging networks because many emerging nations use coal-based electricity. Cost-effective and scalable alternatives like solar-powered charging stations can optimize EVs' environmental benefits while addressing energy dependability concerns. In poorer countries, longitudinal studies are needed to assess the economic effects of EV adoption. Research should examine how EV adoption affects local manufacturing, job generation, and economic growth. Understanding these dynamics can help policymakers create sustainable environmental and economic solutions.

**Author Contributions:** Conceptualization, T.N, and M.S.; methodology, M.S.; software, M.S. and T.N.; validation, M.S. and T.N.; writing—original draft preparation, T.N, and M.S.; writing—review and editing, M.S., T.N, and All authors have read and agreed to the published version of this manuscript.

**Funding:** This research received no external funding.

**Conflicts of Interest:** The authors declare no conflicts of interest.

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