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Sustainability Analytics and Carbon Footprint Reduction in U.S. Car Rental Fleet Operations: A Natural Resource-Based View and Human Capital Theory Analysis

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ABSTRACT

This paper examines sustainability analytics adoption as the independent variable and fleet carbon footprint reduction as the dependent variable in United States car rental fleet operations, with fuel efficiency per vehicle as a secondary dependent variable. The United States transportation sector accounts for approximately 28 percent of total national greenhouse gas emissions, making it the single largest contributing sector. Car rental fleets are an operationally concentrated segment of road transportation in which data-driven sustainability interventions can generate measurable emissions reductions per vehicle, per rental day, and per operator fleet. Drawing on the Natural Resource-Based View of the firm and Human Capital Theory, this paper conducts a systematic narrative literature review of peer-reviewed research on fleet sustainability analytics, electric vehicle adoption, telematics-based efficiency monitoring, and carbon footprint measurement. Five sustainability analytics tool categories are reviewed: telematics and driver behavior monitoring, carbon footprint calculation and reporting, predictive maintenance for efficiency preservation, fleet composition optimization for EV transition planning, and route and utilization optimization. The Technology-Organization-Environment framework is applied to map barriers to effective adoption. Five hypotheses are developed and an empirical validation design specifying variable measurement, data sources, and analytical approaches is proposed. The paper finds that sustainability analytics adoption in car rental operations is constrained primarily by the absence of regulatory mandates, data fragmentation across fleet management systems, and the absence of sustainability management capability in operations staff. The paper contributes the first integrated sustainability analytics framework specific to car rental fleet operations.

Keywords: Decarbonization strategy; ESG reporting frameworks; EV adoption management; Green transport innovation; Telematics efficiency monitoring

INTRODUCTION

The United States transportation sector is the largest single source of national greenhouse gas emissions, accounting for approximately 28 percent of total United States GHG emissions in 2022 and 1.86 billion metric tons of CO2 in 2024 (EPA, 2024a; EIA, 2024). Despite a decline of more than 8 percent from the 2007 peak, United States transportation emissions remain substantially above their long-run net-zero compatible trajectory. Road vehicles, specifically passenger cars and light-duty trucks, account for nearly 60 percent of transportation sector emissions, making vehicle fleet management one of the highest-leverage intervention points available to organizations that manage large numbers of road vehicles.

Car rental fleet operators are among the most significant institutional managers of passenger vehicle fleets in the United States. The United States car rental market generated revenues of approximately $43.9 billion in 2024 (Grand View Research, 2024), with the five largest operators managing fleets of hundreds of thousands of vehicles each. These fleets are not merely concentrated sources of road transport emissions; they are also uniquely positioned to benefit from sustainability analytics adoption. Unlike diffuse private vehicle ownership, rental fleet emissions are concentrated, measurable, and manageable at the operator level. Telematics systems that monitor fuel consumption, driver behavior, idle time, and vehicle efficiency can generate the data inputs for fleet-level carbon footprint calculation, emissions benchmarking, and evidence-based sustainability decision-making.

This paper examines sustainability analytics adoption as the independent variable and fleet carbon footprint reduction as the dependent variable in United States car rental fleet operations. Sustainability analytics adoption is defined as the degree to which a car rental operator has deployed data analytics tools that measure, monitor, and optimize the environmental performance of its fleet, including telematics-based efficiency monitoring, carbon footprint calculation and reporting, predictive maintenance for efficiency preservation, fleet composition optimization for electric vehicle transition planning, and route and utilization optimization to reduce vehicle-miles traveled. Fleet carbon footprint reduction is operationalized as the change in CO2 emissions per vehicle per rental day and per rental transaction, measured against a documented baseline using EPA-verified emission factors.

The paper draws on the Natural Resource-Based View of the firm (Hart, 1995), which extends Barney's (1991) Resource-Based View to incorporate the natural environment as a constraint and strategic opportunity, to explain why sustainability analytics capability generates competitive advantage in the current regulatory, competitive, and investor environment. Human Capital Theory (Becker, 1964; Schultz, 1961) explains why the sustainability management capability required to govern fleet analytics and translate data outputs into emission reduction decisions is systematically underprovided in the current car rental operating environment. The Technology-Organization-Environment framework (Tornatzky and Fleischer, 1990) maps the specific barriers preventing effective adoption.

The paper is organized as follows. Section 2 presents the industry and environmental context. Section 3 presents the theoretical framework. Section 4 reviews the literature. Section 5 maps the five sustainability analytics tool categories. Section 6 applies the TOE framework to adoption barriers. Section 7 develops five hypotheses. Section 8 presents the empirical validation design. Section 9 presents the implementation roadmap. Section 10 discusses implications. Section 11 concludes.

INDUSTRY AND ENVIRONMENTAL CONTEXT

U.S. Transportation Emissions and the Car Rental Sector

Table 1 presents verified statistics establishing the environmental and market context for this analysis.

Table 1. U.S. Transportation Emissions and Car Rental Market Context (2022 to 2025)

Metric	Value	Source
U.S. transportation GHG share of total U.S. emissions (2022)	28% (the largest single sector)	EPA (2024a)
U.S. transportation CO2 emissions (2024)	1.86 billion metric tons CO2	EIA (2024)
Decrease in U.S. transportation emissions (2024 vs. peak)	More than 8% below 2007 peak	EIA (2024)
Road vehicles' share of U.S. transportation GHG (2022)	Passenger cars and light trucks: nearly 60%	EPA (2024a)
Global EV sales (2024)	More than 17 million; 20% of all new car sales	IEA (2025)
U.S. EV sales (2024)	1.6 million; more than 10% of new car sales	IEA (2025)
Global road sector CO2 emissions (2024)	Just over 6 Gt CO2; 8% higher than 2015	IEA (2024b)
U.S. car rental market revenue (2024)	$43.9 billion	Grand View Research (2024)
Online booking share of U.S. car rental revenue (2024)	72.23%	Mordor Intelligence (2025)
Euromonitor global car rental market forecast growth (to 2029)	20% growth to USD 108 billion	Euromonitor International (2024)

Sources: EPA (2024a); EIA (2024); IEA (2024b; 2025); Grand View Research (2024); Euromonitor International (2024); Mordor Intelligence (2025).

The statistics in Table 1 establish a critical context for this paper's argument. Global EV sales exceeded 17 million in 2024 with a sales share of more than 20 percent (IEA, 2025), demonstrating that the electric vehicle transition has passed the early adoption threshold and entered the mass-market phase. United States EV sales reached 1.6 million in 2024, exceeding 10 percent of new car sales. For car rental fleet operators, this trajectory creates both a strategic opportunity and a strategic necessity: operators that proactively manage their EV transition with sustainability analytics can reduce fleet emissions and total cost of ownership simultaneously, while operators that do not adapt face increasing regulatory, reputational, and financial risk as the automotive market continues to electrify.

The IEA (2024b) documents that global road sector CO2 emissions were just over 6 Gt CO2 in 2024, 8 percent higher than 2015, and that emissions need to fall by nearly one-third by 2030 to align with the Net Zero Emissions scenario. This trajectory requires not only EV adoption but active management of efficiency in the existing vehicle fleet, including idling reduction, driver behavior optimization, and route efficiency improvements, which are precisely the operational domains where sustainability analytics generates measurable near-term emission reductions even before fleet electrification is complete.

The Car Rental Sector's Sustainability Position

Car rental operators face a distinctive sustainability challenge that differs structurally from both private vehicle ownership and commercial trucking. Unlike private vehicles, rental cars are managed institutionally, enabling centralized sustainability analytics deployment. Unlike commercial trucking, rental car fleets serve leisure and business travelers rather than freight logistics, creating customer-facing sustainability expectations that are increasingly reflected in corporate travel policy requirements and consumer booking decisions.

Euromonitor International (2024) confirms that the global car rental market forecast includes 20 percent growth to USD 108 billion through 2029, with EV transition and digital operational infrastructure identified as key competitive factors. Soppert, Oliveira, Angeles, and Steinhardt (2024), in the Journal of Business Economics, analyze the combined car rental and car sharing business model, a business model that directly increases fleet utilization and reduces the total number of vehicles required for a given level of mobility service, thereby reducing the carbon intensity per trip served. Their analysis demonstrates that fleet optimization at the strategic level generates both cost and sustainability benefits, establishing the theoretical foundation for fleet composition analytics as a sustainability tool.

THEORETICAL FRAMEWORK

Natural Resource-Based View of the Firm

The Natural Resource-Based View (Hart, 1995), published in the Academy of Management Review, extends Barney's (1991) Resource-Based View to incorporate the natural environment as a strategic constraint and opportunity. Hart (1995) identifies three interconnected strategic capabilities that generate competitive advantage in the natural environment: pollution prevention, product stewardship, and sustainable development. Applied to car rental fleet operations, each capability maps directly onto a sustainability analytics domain.

Pollution prevention in the fleet context corresponds to operational efficiency improvements that reduce emissions per vehicle-mile, including idle time reduction, driver behavior optimization, tire pressure monitoring, and predictive maintenance to preserve rated fuel efficiency. Hart (1995) argues that pollution prevention capabilities are valuable because they simultaneously reduce environmental impact and operating costs, the dual benefit structure that makes telematics-based fleet efficiency analytics a financially justified sustainability investment.

Product stewardship corresponds to life-cycle thinking about fleet composition, specifically the management of vehicle procurement, EV transition planning, and end-of-life vehicle disposition in a way that minimizes total fleet lifecycle emissions. Fleet composition optimization analytics, which model EV versus internal combustion engine vehicle economics and emissions across the vehicle lifecycle, are the operational expression of product stewardship capability in car rental fleet management.

Sustainable development corresponds to the strategic positioning of the firm's fleet operations within the trajectory of the broader energy and transportation system transition. Car rental operators that develop

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sustainability analytics capability aligned with EPA emission reporting standards, IEA Net Zero Scenario benchmarks, and Science Based Targets methodology are building the strategic capability required to maintain competitive position as investor ESG requirements, corporate travel policy sustainability criteria, and regulatory reporting mandates intensify.

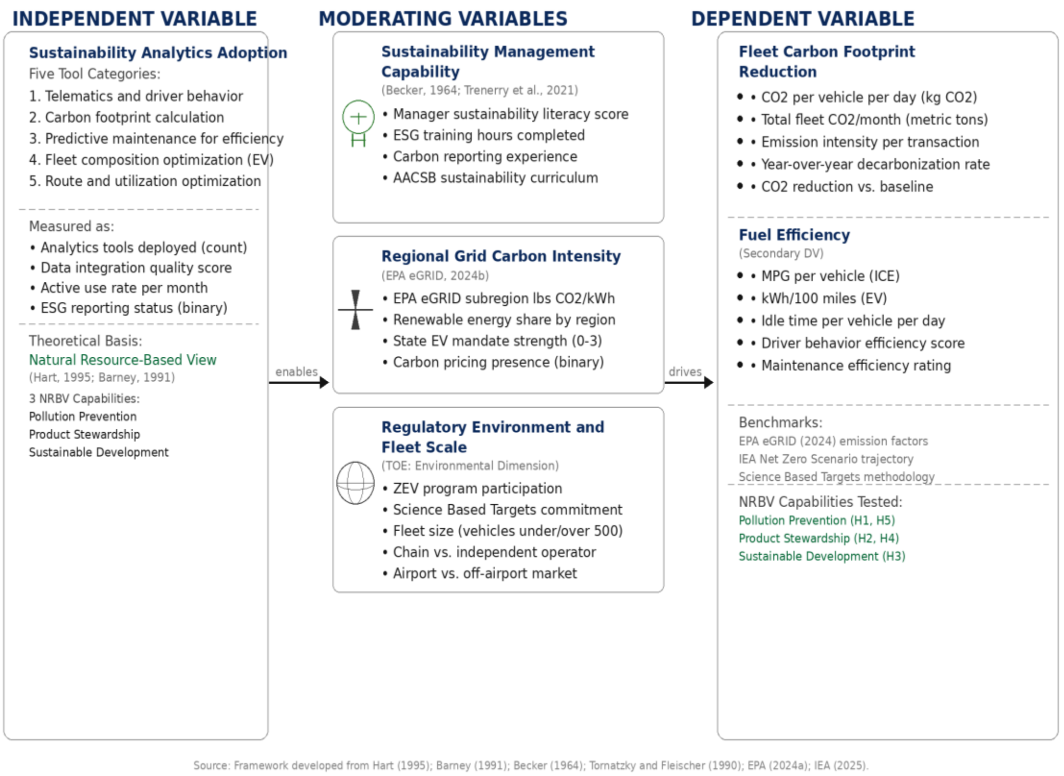
Human Capital Theory and Sustainability Management Capability

Human Capital Theory (Becker, 1964; Schultz, 1961) provides the complementary explanation for why sustainability analytics capability, even when deployed at the technology level, fails to generate its theoretical emission reduction outcomes in the absence of complementary human capability investment. Fleet operations managers who receive carbon footprint reports from telematics platforms but lack the training to interpret emission intensity metrics, evaluate EV total cost of ownership analyses, or apply EPA eGRID carbon intensity data to charging strategy decisions cannot translate the analytical output into emission reduction decisions.

Trenerry, Chng, Wang, Suhaila, Lim, Lu, and Oh (2021) identify skills and training as one of five critical individual-level factors enabling organizational digital transformation outcomes. Their finding that employee training quality directly determines whether technology deployment generates its intended performance benefits is directly applicable to sustainability analytics: the deployment of carbon footprint calculation platforms without parallel development of sustainability literacy in operations managers produces data that is generated but not acted upon.

The Human Capital Theory underinvestment prediction (Becker, 1964) applies to sustainability management capability development with particular force in high-turnover service operations: the expected tenure of a trained operations manager may be insufficient to recoup the training investment before the employee departs, creating a systematic underinvestment in the sustainability literacy required to govern fleet analytics and achieve the emission reduction outcomes that the analytics platforms are designed to generate. Figure 1 presents the integrated conceptual framework.

Figure 1. Conceptual Framework: Sustainability Analytics Adoption and Fleet Carbon Footprint Reduction in U.S. Car Rental Operations



Source: Framework developed from Hart (1995); Barney (1991); Becker (1964); Tornatzky and Fleischer (1990); Trenerry et al. (2021); IEA (2025); EPA (2024a).

LITERATURE REVIEW

Sustainability Analytics in Fleet Operations

The application of data analytics to fleet sustainability management has expanded substantially with the proliferation of telematics platforms, real-time vehicle diagnostics, and electric vehicle management systems. The core analytical challenge in fleet sustainability management is converting raw operational data, specifically fuel consumption records, vehicle-miles traveled, electricity consumption, and idle time, into verified carbon footprint metrics that meet the methodological standards required for ESG reporting and regulatory compliance.

The EPA (2024b) eGRID database provides the verified emission factor infrastructure required for fleet carbon footprint calculation, specifying CO2 intensity per kilowatt-hour by electricity subregion across the United States. This regional variation in grid carbon intensity is analytically significant for car rental EV fleet management: the same electric vehicle, charged from different regional grids, produces substantially different lifecycle CO2 per mile. Fleet composition optimization analytics that incorporate regional eGRID carbon intensity data can identify the operating locations where EV adoption generates the greatest carbon reduction per dollar of transition investment.

The IEA (2024b) Breakthrough Agenda Report on Road Transport documents that road sector emissions grew 0.2 percent annually from 2019 to 2024, substantially below the 1.7 percent pre-pandemic growth rate, partly due to the acceleration of EV adoption globally. Electric car sales grew more than 25 percent year-on-year in 2024 to exceed 17 million vehicles, reaching a global sales share above 20 percent (IEA, 2025). For car rental fleet operators, this market trajectory means that EV options are increasingly available across vehicle classes and price points, removing the previous constraint that EV adoption in rental fleets was limited to a narrow set of premium or specialty vehicles.

Electric Vehicle Transition in Commercial Fleets

The transition of car rental fleets from internal combustion engine vehicles to electric vehicles represents the highest-leverage long-term sustainability action available to fleet operators, generating emission reductions that persist across the vehicle lifecycle rather than the per-trip efficiency improvements achievable through telematics-based behavior monitoring alone. The IEA (2025) Global EV Outlook 2025 documents that the global EV fleet reached approximately 58 million at the end of 2024, with the stock of electric cars displacing over one million barrels per day of oil consumption. This displacement magnitude establishes the aggregate impact potential of fleet electrification as a sustainability strategy.

The regional variation in electricity grid carbon intensity documented by the EPA (2024b) eGRID database creates a specific analytical challenge for car rental operators with multi-location fleets. An EV fleet in a high-renewable-energy grid region such as the Pacific Northwest generates substantially lower lifecycle CO2 per mile than the same fleet operating in a coal-intensive grid region. Fleet composition optimization analytics that incorporate location-specific grid carbon intensity can sequence EV transition investments to prioritize the operating locations where electrification generates the greatest verified emission reduction, maximizing the carbon impact per dollar of transition investment.

Soppert, Oliveira, Angeles, and Steinhardt (2024) demonstrate that combining car rental and car sharing operations with a unified fleet reduces total vehicles required for a given level of mobility service, directly reducing fleet carbon intensity per trip served. Their analysis, published in the Journal of Business Economics, provides an empirical demonstration that fleet optimization at the strategic level generates simultaneous cost and sustainability benefits, reinforcing the Natural Resource-Based View prediction that pollution prevention capabilities create business value rather than merely imposing cost.

Literature Gap: Car Rental Sustainability Analytics

The application of sustainability analytics frameworks to car rental fleet management specifically is absent from the academic literature. Prior work has addressed fleet sustainability in trucking and logistics contexts, EV adoption in urban mobility contexts, and ESG reporting frameworks at the corporate level. The specific operational analytics required to manage a multi-location rental fleet toward verified carbon footprint reduction outcomes, including the integration of telematics data with EPA eGRID emission factors, the fleet composition optimization challenge of sequencing EV transitions across locations with different grid carbon intensities, and the sustainability management capability development required to govern these systems, have not been addressed in the peer-reviewed literature. This paper addresses that gap.

SUSTAINABILITY ANALYTICS TOOL CATEGORIES FOR CAR RENTAL FLEET OPERATIONS

Based on the literature review and the Natural Resource-Based View framework, five sustainability analytics tool categories are identified as applicable to car rental fleet operations. Table 2 presents the mapping of tool categories to operational applications, sustainability outcomes, and data requirements.

Table 2. Sustainability Analytics Tool Categories for U.S. Car Rental Fleet Operations

Analytics Tool / Approach	Application in Fleet Operations	Sustainability Outcome	Data Required
Telematics and vehicle GPS tracking	Real-time monitoring of vehicle idling, speed, route efficiency, and fuel or energy consumption per trip	Idle time reduction; fuel consumption monitoring; EV energy use tracking; driver behavior scoring for efficiency	OBD-II or embedded telematics; GPS trip data; fuel card transactions; EV charging records
Carbon footprint calculation and reporting	Aggregation of fuel consumption, electricity use, and vehicle-miles traveled data to calculate total fleet CO2 and CO2-equivalent emissions at vehicle, location, and fleet levels	Fleet-level carbon footprint for ESG reporting; emission intensity per rental day; year-over-year decarbonization progress	Fuel type and consumption records; electricity grid carbon intensity (EPA eGRID); fleet composition data
Predictive maintenance analytics for efficiency	ML models predicting component wear and tire pressure degradation to prevent efficiency losses from poor vehicle condition	Fuel efficiency maintained at rated levels; tire pressure monitoring reduces rolling resistance and fuel waste; prevents emissions-intensive emergency repairs	Telematics sensor data; maintenance records; OBD-II diagnostic data; TPMS data
Fleet composition optimization analytics	Scenario modeling of EV versus ICE vehicle mix against demand patterns, charging infrastructure, and total cost of ownership including carbon cost	Optimal EV penetration rate for each operating location; total cost of ownership comparison including carbon pricing scenarios; charging infrastructure sizing	Demand pattern data; electricity grid carbon intensity by location; EV vs. ICE total cost of ownership; range and charging time constraints
Route and utilization optimization	Algorithms matching rental vehicles to reservations and delivery routes to minimize vehicle-miles traveled and maximize fleet utilization	Reduced empty repositioning miles; lower per-rental carbon footprint; improved fleet utilization reducing the need for additional vehicles	Reservation data; delivery and collection routing; fleet location data; demand forecasting outputs

Sources: Synthesized from EPA (2024a; 2024b); IEA (2024b; 2025); Soppert, Oliveira, Angeles and Steinhardt (2024); Hart (1995); Grand View Research (2024); Euromonitor International (2024).

The five tool categories form a progression from near-term operational efficiency interventions to long-term fleet transformation. Categories 1 and 3, telematics monitoring and predictive maintenance, generate immediate emission reduction benefits from the existing fleet without requiring vehicle replacement or infrastructure investment. Categories 2 and 4, carbon footprint reporting and fleet composition optimization, provide the measurement and planning infrastructure required to manage the EV transition strategically. Category 5, route

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and utilization optimization, reduces the total vehicle-miles traveled required to serve a given volume of rental demand, reducing fleet emissions independent of fleet composition.

The Hart (1995) Natural Resource-Based View framework maps cleanly onto this five-category structure. Pollution prevention corresponds to Categories 1, 3, and 5, which generate efficiency improvements and emission reductions within the current fleet. Product stewardship corresponds to Categories 2 and 4, which apply life-cycle thinking to fleet composition decisions and ESG reporting. The integration of all five categories constitutes the sustainable development capability that the Natural Resource-Based View identifies as the highest-order source of competitive advantage in the natural environment.

TOE FRAMEWORK ANALYSIS: BARRIERS TO SUSTAINABILITY ANALYTICS ADOPTION

Table 3 maps the specific barriers constraining sustainability analytics adoption in U.S. car rental fleet operations across the Technology-Organization-Environment framework dimensions.

Table 3. Barriers to Sustainability Analytics Adoption in U.S. Car Rental Fleet Operations: TOE Framework Analysis

Barrier	Dimension	Manifestation in Car Rental Operations	Evidence
Absence of mandatory fleet carbon reporting standards	Environmental	No U.S. federal requirement for car rental operators to report fleet-level GHG emissions; state-level requirements vary significantly; operators have no compliance-driven incentive to invest in carbon analytics infrastructure	EPA (2024a); Euromonitor International (2024)
Fleet composition lock-in from long-term vehicle procurement cycles	Technological/ Organizational	Car rental operators procure vehicles on multi-year cycles; EV transition requires parallel charging infrastructure investment; operators cannot rapidly shift fleet composition even if sustainability analytics identify the optimal EV mix	IEA (2025); Euromonitor International (2024)
Charging infrastructure availability at rental locations	Technological	Most car rental operating locations, particularly off-airport locations, lack on-site EV charging infrastructure; charging time constraints affect rental readiness and fleet availability in ways that ICE fleet management does not face	IEA (2024b); Grand View Research (2024)
Data fragmentation across fleet management systems	Technological	Fuel consumption, maintenance, telematics, and reservation data are managed in separate systems at most operators; carbon footprint calculation requires integrated data that is not available from fragmented sources	Soppert, Oliveira, Angeles and Steinhardt (2024)
Absence of management capability for sustainability analytics	Organizational	Operations managers at car rental locations are trained in fleet management and customer service; they have not been trained to interpret carbon footprint reports, evaluate EV total cost of ownership, or apply sustainability analytics to operational decisions	Becker (1964); Trenerry et al. (2021)
Market competition and margin pressure limiting discretionary investment	Environmental	Price competition among car rental operators limits the discretionary capital available for sustainability technology investment; operators that absorb EV transition costs without regulatory mandates face competitive disadvantage against operators that do not	Euromonitor International (2024); Grand View Research (2024)

Sources: Tornatzky and Fleischer (1990); Becker (1964); EPA (2024a); IEA (2025); Soppert, Oliveira, Angeles and Steinhardt (2024); Grand View Research (2024); Euromonitor International (2024); Trenerry et al. (2021).

The TOE analysis reveals that the environmental dimension barriers are more significant for sustainability analytics adoption than for operational analytics adoption in other domains. Operational analytics tools, such as revenue management systems and fleet scheduling platforms, generate direct cost and revenue benefits that justify investment without external mandates. Sustainability analytics tools, by contrast, generate benefits that are partially external to the investing firm, specifically the climate benefits of emission reduction. Without regulatory mandates or carbon pricing mechanisms that internalize these external benefits, the business case for sustainability analytics investment is weaker than for operational analytics, creating the systematic underinvestment that the TOE environmental dimension analysis predicts.

PROPOSED RESEARCH HYPOTHESES

Based on the theoretical frameworks in Section 3, the literature review in Section 4, and the TOE barrier analysis in Section 6, five hypotheses are proposed. Table 4 presents the complete hypothesis set.

Table 4. Research Hypotheses: Sustainability Analytics Adoption and Fleet Carbon Footprint Reduction in U.S. Car Rental Operations

Hypothesis	Statement	Theoretical Basis
H1	Higher levels of sustainability analytics adoption are positively associated with fleet carbon footprint reduction outcomes, measured as CO_2 emissions per vehicle per day and per rental transaction, in U.S. car rental operations	Natural Resource-Based View (Hart, 1995); Human Capital Theory (Becker, 1964)
H2	Higher levels of EV fleet penetration are positively associated with fleet carbon footprint reduction, with the magnitude of the effect moderated by the carbon intensity of the regional electricity grid at the operating location	IEA (2025); EPA (2024b); Natural Resource-Based View (Hart, 1995)
H3	The relationship between sustainability analytics adoption and fleet carbon footprint reduction is positively moderated by sustainability management capability, such that higher capability strengthens the analytics-emissions reduction relationship	Brynjolfsson, Mitchell and Rock (2018); Becker (1964)
H4	Fleet composition optimization analytics adoption is positively associated with total cost of ownership reduction when carbon pricing scenarios are incorporated, and this relationship is stronger in regulatory environments with active carbon pricing or EV mandate policies	Soppert, Oliveira, Angeles and Steinhardt (2024); IEA (2024b)
H5	Telematics-based driver behavior analytics adoption is positively associated with per-vehicle fuel efficiency improvement in ICE fleets, independent of fleet composition changes	Euromonitor International (2024); EPA (2024a)

Sources: Hart (1995); Barney (1991); Becker (1964); IEA (2025); EPA (2024b); Soppert, Oliveira, Angeles and Steinhardt (2024); Tornatzky and Fleischer (1990); Brynjolfsson, Mitchell and Rock (2018).

H1 tests the core analytics-emissions relationship at the fleet level. The Natural Resource-Based View prediction that pollution prevention capabilities generate measurable environmental performance improvements is tested using verified fleet-level CO_2 data against EPA emission factor benchmarks. H2 tests the EV-emissions relationship with grid carbon intensity moderation, capturing the spatial heterogeneity in EV emission benefits documented by the EPA eGRID database.

H3 tests the Human Capital Theory prediction that sustainability management capability moderates the analytics-performance relationship. This is the paper's most novel contribution: it specifically predicts that sustainability analytics adoption without complementary capability development does not generate its theoretical emission reduction outcomes, a prediction that directly parallels the technology-capability complementarity finding of Brynjolfsson, Mitchell, and Rock (2018) in the AI adoption context.

H4 tests the regulatory environment moderation prediction, capturing the Natural Resource-Based View argument that sustainability capabilities generate stronger competitive returns in more stringent regulatory environments. H5 tests the telematics-fuel efficiency relationship in ICE fleets, providing a near-term testable prediction that does not require EV adoption and is therefore actionable for operators at any stage of fleet electrification.

PROPOSED EMPIRICAL VALIDATION METHODOLOGY

Table 5 presents the variable definitions and measurement approaches for empirical validation of the five hypotheses.

Table 5. Variable Definitions and Measurement Approaches

Variable	Operationalization	Data Source	Benchmark
IV: Sustainability analytics adoption	Composite index: sustainability analytics tools deployed (telematics, carbon footprint reporting, EV optimization, route analytics), data integration quality, active use rate (10-item scale)	Operator survey; technology inventory audit	AACSB (2020) environmental management standards
DV1: Fleet carbon footprint	CO2 emissions per vehicle per rental day (kg CO2); total fleet CO2 per month (metric tons); year-over-year decarbonization rate	Fuel consumption records + EPA emission factors (EPA 2024b); EV electricity consumption + EPA eGRID carbon intensity by region	EPA (2024a) sector benchmarks; IEA (2025) fleet average
DV2: Fuel efficiency per vehicle	Miles per gallon or kilowatt-hours per 100 miles for ICE and EV vehicles respectively; idle time per vehicle per day; driver behavior efficiency score	Telematics data; fuel card records; EV charging records	OEM rated efficiency as baseline; telematics fleet benchmarks
DV3: EV fleet penetration rate	Percentage of total fleet that is fully electric or plug-in hybrid; year-over-year EV addition rate	Fleet composition records; vehicle registration data	IEA (2025) U.S. market share benchmark (10% of new sales)
Moderator: Sustainability management capability	Manager sustainability literacy assessment score; ESG training hours completed; sustainability reporting experience (adapted from Trenerry et al., 2021)	Survey instrument; HR training records	AACSB (2020) sustainability curriculum standards
Moderator: Regional grid carbon intensity	EPA eGRID subregion average pounds of CO2 per kilowatt-hour	EPA eGRID (2024), specific subregion for each operating location	EPA eGRID (2024) national and regional averages
Moderator: Regulatory environment	State-level EV mandate strength (0 to 3 scale); carbon pricing presence (binary); ZEV program participation	ICCT ZEV policy tracker; state legislative records	California Advanced Clean Cars program as high-mandate benchmark
Control variables	Fleet size; market segment (airport vs. off-airport); operator type (chain vs. independent); geographic region	Operator records; Grand View Research (2024)	Stratification by fleet size and market segment

Sources: EPA (2024a; 2024b); IEA (2025); Grand View Research (2024); Becker (1964); Tornatzky and Fleischer (1990); AACSB (2020); Trenerry et al. (2021).

The proposed empirical design uses a two-phase approach. Phase 1 deploys a cross-sectional survey of car rental operations managers and fleet managers at a minimum of 100 United States car rental properties, stratified by fleet size, operator type, and market segment, measuring sustainability analytics adoption, sustainability management capability, and self-reported fleet performance outcomes. Phase 2 uses operational fleet records from participating operators to calculate verified fleet-level carbon footprint using EPA emission factors, enabling direct comparison of emission intensity across high and low analytics adoption properties.

The use of EPA eGRID carbon intensity data as a moderating variable in H2 introduces a spatial element to the analysis that is novel in the fleet sustainability literature: it enables the emission reduction effect of EV adoption to be distinguished from the effect of analytics adoption, and it enables the identification of operating locations where EV investment generates disproportionate carbon benefit due to favorable grid conditions.

A FIVE-STAGE SUSTAINABILITY ANALYTICS IMPLEMENTATION ROADMAP

Table 6 presents the five-stage implementation roadmap for car rental fleet sustainability analytics, connecting each stage to specific emission reduction milestones and analytics tools.

Table 6. Five-Stage Sustainability Analytics Implementation Roadmap for U.S. Car Rental Fleet Operations

Implementation Stage	Timeline	Activities	Key Milestone
Stage 1: Emissions Baseline	Months 1-3	Integrate fuel consumption, vehicle-miles traveled, and electricity data; calculate current fleet-level CO2 using EPA emission factors; establish vehicle-level emission intensity baseline; install telematics where absent	Fleet-level carbon footprint baseline established; emission intensity per rental day documented for all vehicle classes
Stage 2: Driver Behavior Analytics	Months 4-6	Deploy telematics-based driver behavior scoring covering idling, hard braking, excessive speed, and route efficiency; establish feedback loop with drivers; integrate with daily fleet management workflows	Measurable reduction in per-vehicle idle time; fuel efficiency benchmarking active; driver coaching program operational
Stage 3: EV Transition Analytics	Months 7-12	Model EV vs. ICE total cost of ownership for each operating location incorporating local grid carbon intensity; identify optimal EV addition rate; assess charging infrastructure requirements; develop vehicle procurement sustainability criteria	EV transition roadmap produced for each location; charging infrastructure plan submitted; first EV additions aligned with model output
Stage 4: Carbon Reporting	Year 2	Implement formal fleet carbon footprint reporting against EPA-verified emission factors; integrate into ESG reporting framework; establish year-over-year decarbonization targets; align with Science Based Targets initiative methodology where applicable	Annual fleet emissions report produced; decarbonization targets set and communicated to stakeholders
Stage 5: Fleet Optimization and Governance	Year 2 and ongoing	Deploy route and utilization optimization to reduce empty repositioning miles; implement fleet composition analytics for ongoing EV mix optimization; establish sustainability KPI dashboard for operations managers	Fleet carbon intensity per rental day declining year-over-year; sustainability analytics integrated into daily operations management workflow

Sources: Hart (1995); Becker (1964); EPA (2024a; 2024b); IEA (2025); AACSB (2020); Soppert, Oliveira, Angeles and Steinhardt (2024); Tornatzky and Fleischer (1990).

The five-stage roadmap addresses the data fragmentation barrier identified in the TOE analysis by front-loading data integration as Stage 1, establishing the emissions baseline that makes all subsequent analytics valuable. Without a documented baseline, sustainability analytics tools cannot demonstrate emission reduction progress, and the Natural Resource-Based View prediction that pollution prevention capabilities generate business value cannot be verified. The baseline establishes both the internal accountability mechanism and the external ESG reporting foundation required for the analytics investment to generate recognized sustainability value.

DISCUSSION

Five implications from this analysis carry significance for car rental operators, fleet managers, policymakers, technology vendors, and future researchers.

First, the Natural Resource-Based View analysis establishes that sustainability analytics capability in car rental fleet operations is not merely a compliance or reputational investment but a source of genuine competitive advantage. The pollution prevention capabilities mapped in the five analytics tool categories generate simultaneous emission reduction and cost reduction, satisfying the Hart (1995) criterion for competitive advantage through environmental strategy. Operators that build verified fleet carbon footprint management capability ahead of mandatory reporting requirements will benefit from lower compliance transition costs when those requirements arrive, and from preferential positioning in corporate travel procurement processes where sustainability criteria are increasingly weighted.

Second, the regional grid carbon intensity finding has a direct practical implication that current fleet management practice does not capture. An EV added to a rental fleet in a high-renewable-energy grid region generates substantially greater verified carbon reduction per vehicle than the same EV added to a coal-intensive grid region. Car rental operators with multi-location fleets that sequence EV additions to prioritize high-renewable-energy locations first can maximize the verified emission reduction per dollar of EV transition investment, generating a stronger ESG reporting narrative while managing transition costs. Fleet composition optimization analytics that incorporate EPA eGRID data enable this spatially optimized sequencing; current practice does not.

Third, the Human Capital Theory analysis identifies sustainability management capability development as the binding constraint on the sustainability analytics investment cycle. The IEA (2025) Global EV Outlook 2025 documents a global EV fleet of approximately 58 million vehicles, demonstrating that the technology infrastructure for fleet electrification is advancing rapidly. The constraining variable is not technology availability but the organizational capability to manage the transition analytically. Car rental operators that invest in sustainability literacy training for their fleet operations teams are building the Human Capital that converts sustainability analytics platforms from data generators into emission reduction decision tools.

Fourth, the Science Based Targets initiative methodology provides a credibility framework for car rental operator sustainability commitments that analytics adoption makes achievable. The SBTi requires organizations to set emissions reduction targets aligned with the Paris Agreement's 1.5-degree pathway, verified against third-party emission factor databases including the EPA eGRID data referenced in this paper's measurement framework. Car rental operators that implement the sustainability analytics roadmap proposed in Section 9 will have the data infrastructure, baseline documentation, and annual reporting capability required to submit credible SBTi commitments, enhancing their investor, corporate client, and regulatory positioning.

Fifth, the industry association coordination argument applies to sustainability analytics adoption with the same force documented in other domains of this research portfolio. Individual car rental operators face the same coordination failure in sustainability investment as in workforce capability development: the full social benefit of fleet emission reduction is not captured by the investing firm, creating systematic underinvestment relative to the socially optimal level. The American Car Rental Association and comparable mobility industry organizations have the institutional capacity to develop shared sustainability reporting frameworks, group telematics procurement arrangements, and industry-wide carbon benchmark databases that reduce per-operator adoption costs and create the external sustainability credentialing that aligns private and social incentives for emission reduction investment.

CONCLUSION

This paper examined sustainability analytics adoption as the independent variable and fleet carbon footprint reduction as the dependent variable in United States car rental fleet operations. Four conclusions stand out.

The United States transportation sector's 28 percent share of national GHG emissions and the car rental sector's position as an institutionally concentrated, analytically manageable segment of road vehicle operations create a specific and tractable opportunity for data-driven emission reduction. The five sustainability analytics tool categories identified in this paper, from telematics-based efficiency monitoring through fleet composition optimization for EV transition, provide a sequenced, verified-data pathway from the current emission baseline to the decarbonization trajectory required by the Net Zero Scenario.

The Natural Resource-Based View analysis establishes that sustainability analytics capability generates competitive advantage through three mechanisms identified by Hart (1995): pollution prevention capabilities that reduce both emissions and operating costs, product stewardship capabilities that manage fleet lifecycle environmental impact, and sustainable development capabilities that position the operator within the long-run trajectory of the transportation system transition. These capabilities satisfy the Barney (1991) VRIN conditions when developed systematically, because the majority of car rental operators have not yet built them.

The Human Capital Theory analysis identifies sustainability management capability development as the binding organizational constraint on emissions reduction outcomes. The TOE barrier analysis confirms that the constraining barriers are organizational and environmental rather than technological: the analytics tools are available, the data infrastructure is deployable, and the EPA emission factor benchmarks are publicly accessible. The constraints are in sustainability literacy among operations staff, data integration quality, and the absence of regulatory mandates that would create compliance-driven investment incentives.

Future research should empirically validate the five hypotheses using the design specified in Section 8, with particular attention to the H2 grid carbon intensity moderation test and the H3 sustainability management capability moderation test. These two predictions, if confirmed empirically, would establish that the spatial optimization of EV transition investment and the complementary development of sustainability management capability are the two highest-leverage interventions available to car rental operators seeking to maximize verified carbon footprint reduction per dollar of sustainability investment.

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