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ADOPTION OF ELECTRIC VEHICLES IN CORPORATE ENTERPRISES: ENHANCING SUSTAINABILITY, ECONOMIC EFFICIENCY, AND OPERATIONAL MANAGEMENT

ADOPCIÓN DEL VEHÍCULO ELÉCTRICO EN LAS EMPRESAS: SOSTENIBILIDAD, EFICIENCIA ECONÓMICA Y GESTIÓN OPERATIVA

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ABSTRACT

The global automotive industry is currently undergoing a transformation driven by a number of factors, including environmental concerns, sustainability targets, and the advent of innovative technologies. The adoption of electric vehicles represents a pivotal aspect of this transformation, offering individual and corporate users in the car rental sector a significant alternative to traditional internal combustion engine vehicles. The economic and operational advantages of electric vehicles, coupled with the opportunity for car rental companies to fulfil their environmental responsibilities, are accelerating the transformation of the automotive industry.

This study presents a case study on the utilization of electric vehicles for long-term car leasing companies for the purpose of providing corporate internal services. The aim is to provide a comprehensive evaluation of the issue from multiple perspectives. The objective of this paper is to provide a comprehensive overview of the concept of electric vehicle leasing, encompassing a range of considerations pertinent to decision-making. These include environmental sustainability, economic advantages, user experience, and operational efficiency.

RESUMEN

La industria automovilística mundial está experimentando una transformación impulsada por las preocupaciones medioambientales, los objetivos de sostenibilidad y las tecnologías innovadoras. La adopción de vehículos eléctricos es un factor clave de esta transformación, ya que ofrece a los usuarios particulares y corporativos del sector del alquiler de coches una importante alternativa a los vehículos tradicionales con motor de combustión interna. Las ventajas económicas y operativas de los vehículos eléctricos, junto con la oportunidad para las empresas de alquiler de coches de cumplir con sus responsabilidades medioambientales, están acelerando esta transformación.

Este artículo presenta un estudio de caso sobre el uso de vehículos eléctricos para empresas de alquiler de coches a largo plazo con fines de servicio interno corporativo. El objetivo es ofrecer una evaluación multidimensional de la cuestión. El artículo también pretende informar a los mecanismos de toma de decisiones sobre el concepto de arrendamiento de vehículos eléctricos en una perspectiva amplia, desde la sostenibilidad medioambiental hasta las ventajas económicas, desde la experiencia del usuario hasta la eficiencia operative.

KEYWORDS / PALABRAS CLAVE

Electric vehicle rental | Electric vehicle use for corporate companies | Sustainable transport concept
Alquiler de vehículos eléctricos | Uso de vehículos eléctricos para empresas | Concepto de transporte sostenible

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1. INTRODUCTION

Transport is one of the sectors that can contribute most rapidly to climate change. Globally, energy-related CO_2 emissions in 2023 were reported to have increased by 1.1% compared to the previous year, a reaching 37.4 billion tons (IEA, 2024). According to data from the Turkish Statistical Institute, Turkiye's total greenhouse gas emissions in 2022 decreased by 2.4% compared to the previous year, reaching a total of 558.3 million tons of CO_2 (TUIK., (June 2024).

While sustainability and innovation are among the main strategies of corporations in the business community, the pressing issues of global warming, environmental pollution and the risk of depletion of fossil fuel resources have led companies to search for more sustainable solutions. It is estimated that approximately 50% of vehicles on the roads today are provided by the services offered by corporate fleet leasing companies. In this context, the car rental sector is particularly well-positioned to spearhead the transition to a sustainable transport paradigm. The transition to low-emission vehicle fleets is regarded as a relatively straightforward method for businesses to reduce their carbon footprint and combat climate change (LeasePlan, 2023). In this context, the adoption of electric vehicles instead of traditional internal combustion engine vehicles, which have constituted the backbone of vehicle fleets for many years in the car rental sector, will not only facilitate the fulfilment of environmental responsibilities of the corporate companies that both provide and use the vehicles, but also provide added value in economic terms.

The growing interest and widespread use of electric vehicles by corporate companies has the effect of significantly reducing the carbon footprint of companies and contributing to improve urban air quality vis-à-vis internal combustion engine vehicles. A study conducted by the European Environment Agency has revealed a consistent decline in the average CO_2 emissions from new passenger cars registered in Europe over recent years. Without any doubt, the primary reason for the 5.3% decline in 2022 compared to the previous year is attributed to the surge in the number of electric vehicles, with electric vehicle registrations reaching 23% of the new car fleet in 2022 (EEA, 2024). Furthermore, in accordance with (EUR-Lex Regulation (EU) 2019/631), more rigorous CO_2 emission targets have been established for vehicle fleets across the EU. These targets include a reduction of 15% in 2025 and 55% in 2030 for cars in comparison to the 2021 baseline. The Union of Concerned Scientists has suggested that the carbon emissions of electric vehicles can be further reduced, contingent on the energy source from which they are charged (Pinto, 2022). Such environmental benefits contribute significantly to the achievement of corporate companies' sustainability goals and fulfilment of their environmental responsibilities.

Furthermore, electric vehicles are economically efficient in the long term, with lower maintenance and repair costs and gains in fuel and energy costs. The International Energy Agency's calculation module, based on the total cost of ownership approach, indicates that the maintenance costs of electric vehicles are on average 40% lower than those of internal combustion engine vehicles (IEA, 2023). A market study was conducted to analyze the periodic maintenance costs of an OEM operating in Turkiye. The study was based on unit prices on periodic maintenance costs for electric vehicles in April 2024. The findings indicated that electric vehicles exhibited a 27% cost advantage in terms of periodic maintenance costs compared to conventional vehicles (sedans) with similar characteristics (Topal, 2023). This is due to the fact that many subcomponents with fewer moving parts do not require maintenance, reducing the need for breakdowns and repairs. It is suggested that the energy costs of electric vehicles are approximately one-third of those of fossil fuels (BloombergNEF, 2024). The International Energy Agency has stated that, in terms of fuel and energy efficiency, the average conditions in electric vehicles are 14.00 kWh/100 km, while those in gasoline vehicles are 6.5 lt/100 km. Furthermore, the IEA has indicated that these cost advantages increase operational profitability and enable more efficient use of resources (IEA, 2023).

The advent of electric vehicles has brought about digital transformation and technological innovations that differentiate them from conventional vehicles. Connected vehicle technologies, autonomous driving systems, and smart charging solutions offer significant advantages, particularly in terms of safety and efficiency. Tesla's autopilot system and other autonomous driving technologies, for instance, have been shown to provide significant gains in these areas (Olorunfemi, 2024). Moreover, according to Gartner's research, smart charging solutions and energy management systems enable companies using electric vehicles to optimize energy consumption, reduce costs, and increase operational efficiency (Gartner, 2014).

Another indirect consequence of the adoption of electric vehicles is the potential for companies that favour them to gain a competitive advantage through the strengthening of their corporate image. As reported by McKinsey & Company, the adoption of environmentally friendly practices enhances the reputation of companies among consumers and business partners (McKinsey, 2022). The emphasis on the use of electric vehicles in sustainability reports is indicative of the seriousness with which companies approach their environmental responsibilities. This situation serves to enhance the brand value of corporate entities and to reinforce customer loyalty. According to the Carbon Disclosure Project, companies that improve their environmental performance become more attractive to investors (CDP, 2023).

Policies and financial incentives that encourage the corporate use of electric vehicles also have the potential to facilitate the adoption of this technology by companies. The European Union's Green Deal and other global sustainability initiatives facilitate the deployment of electric vehicles. Tax breaks, subsidies, and incentives for the development of charging infrastructure support companies in their transition to electric vehicles (European Commission, 2023). In a similar vein, the United States Environmental Protection Agency has implemented a number of incentive programs designed to facilitate the deployment of electric vehicles. (IEA, 2022). Such regulatory policies are considered to contribute to the economically sustainable growth of companies.

The adoption of electric vehicles by corporate entities also contributes to strategic transformation processes. In this regard, the PwC Turkiye Sustainability Report suggests that companies can develop robust and more sustainable business models by integrating electric vehicle fleets into their digital transformation processes (PwC, 2023). It is suggested that the adoption of electric vehicles will enable companies to strengthen their market position by enhancing their competitive advantage through the introduction of innovative solutions in areas such as energy management, data analytics, and smart charging.

2. SECTORAL OUTLOOK IN TURKIYE

The 2023 Operational Leasing Sector Report, prepared by TOKDER, indicates that the average unit vehicle purchase price for leased vehicles in Turkiye is 30.683 Euro . On a sectoral basis, the report indicates that 254,000 vehicles were leased, representing a 3.7% increase compared to the previous year. It is indicated that the proportion of hybrid and electric vehicles in the vehicle fleet of the sector is increasing at a rapid pace. The 2023 report by TOKDER indicates that 44.2% of the sector's vehicle fleet is comprised of diesel-powered vehicles, 46.2% of petrol vehicles, and 9.4% of hybrid and electric vehicles (TOKDER, 2023).

Conversely, data from the Turkish Statistical Institute indicates that 65.3% of the 343,585 cars registered between January 2024 and April 2024 were powered by gasoline, 13.2% were hybrid, 12.8% were diesel, 7.5% were electric, and 1.2% were powered by LPG. As of April 2024, 35.1% of the 15,562,640 cars registered for use on the road were diesel, 32.9% were LPG, 29.3% were gasoline, 1.7% were hybrid, and 0.7% were electric (TUIK, (April, 2024).

The Car Rental Sector Report prepared by Oyak Yatırım indicates that diesel vehicles, which currently constitute the largest share of the long-term car rental sector, will be less preferred over petrol, hybrid, and electric vehicles by 2020 (KPMG Borlease., 2022). In fact, while approximately 95% of the operational leasing market was comprised of diesel-fueled vehicles in 2017, this proportion decreased to 62% in 2022. The share of gasoline-fueled vehicles was 30.1%, hybrid vehicles 7.4% and electric vehicles 0.4% in 2022.

3. CONTEXTUAL BACKGROUND AND RELATED WORKS

The advent of electric vehicles represents one of the most significant technological innovations in the pursuit of contemporary energy efficiency and sustainable transport objectives. In comparison to conventional internal combustion engine vehicles, electric vehicles demonstrate superior efficiency in energy conversion processes, resulting in a notable reduction in fossil fuel consumption and associated greenhouse gas emissions. In Turkiye, it has been reported that cars used for individual purposes travel an average of 10,000 to 15,000 kilometers per year, while vehicles leased by corporate companies travel 30,000 to 40,000 kilometers per year (Budget, 2024).

The energy consumption of electric vehicles is characterized by a complex and variable structure, which is influenced by a number of dynamic factors. These include battery technology, efficiency of charging infrastructure, driving habits, road conditions, and carbon intensity of the electricity source used. These factors are of critical importance for the full realization of the environmental and economic advantages of electric vehicles. In particular, the integration of renewable energy sources is critical to achieve the greatest possible positive impact of electric vehicles on total energy consumption and carbon emissions. This section presents a comprehensive analysis of the current literature on the energy consumption of electric vehicles. It also presents innovative strategies, advanced technological developments, and feasible policy recommendations based on corporate use.

The driving range of electric vehicles can be optimized by varying the efficiency and performance of the drive battery. In this context, the ambient temperature and the utilization of the HVAC (Heating, Ventilating and Air Conditioning) system for electric vehicles have a direct impact on the driving range. A number of studies in the literature have investigated the effects of ambient temperature on the energy consumption of electric vehicles. It is stated that the temperature range of 20 °C to 30 °C is the optimum operating range for electric vehicle drive batteries. The energy consumption of the drive battery increases by 5.4% in summer conditions, and 12.0% in winter conditions when the HVAC system is activated (Lee et al., 2024).

The results of the experimental analyses conducted by Lee et al. on a compact crossover SUV equipped with a 72.6 kWh lithium-ion battery pack indicate that the lowest battery energy consumption (1.56 kWh) occurs at 27.5 °C and the highest (2.91 kWh) at -15 °C in urban use. In rural use, the lowest battery energy consumption (2.17 kWh) occurs at 23 °C, and the highest (3.32 kWh) at -15 °C. Finally, in motorway use, the lowest battery energy consumption (3.30 kWh) occurs at 21.5 °C, and the highest (5.70 kWh) at -15 °C (Lee et al., 2024). Furthermore, a comparison of the results of the test performed at 29 °C with the air conditioning system off and the test performed at 28 °C with the air conditioning system on reveals that the air conditioning effect results in 5.4% higher battery energy consumption. Similarly, the effect of the heating function is also considered. The test performed at 4 °C with the heating system switched off resulted in 12.0% higher battery consumption in the second case compared to the test performed at 5 °C with the heating system switched on. The results indicate that the battery energy consumption will be higher when the heater is used in winter than when the air conditioning system is operated in summer (Lee et al., 2024).

It has been suggested that the extremely low temperatures at which electric vehicles are operated increase the internal resistance of the drive battery, resulting in augmented power losses and diminished available drive battery capacity (Jaguemont et al.,2016) (Lu et al., 2020). This causes an increase in the total energy consumption of the vehicle, which consequently leads to a reduction in the driving range (Ji et al., 2013). Furthermore, the increase in air density at low temperatures leads to an increase in rolling resistance of the tires, and an increase in aerodynamic friction forces on the vehicle, which likewise increase the unit energy consumption.

A vehicle simulation revealed that energy consumption at a temperature of -10 °C was 18.7% higher than at 25 °C. It is hypothesized that the elevated internal resistance of the drive battery at low temperatures results in increased discharge currents to meet power demands and a reduced charging capacity during regenerative braking. (Babu et al., 2022).

In a study conducted by (Xu et al., 2023), measurements were made using a Tesla Model 3 in a chassis dynamometer. The results showed that, when simulations were based on different driving profiles, the range values were 218 miles at 30°C, 211 miles at 35°C (a 3.3% decrease), and 189 miles at 40°C (a 13.4% decrease) (Xu et al., 2023).

A series of chassis dynamometer tests were conducted on a Nissan Leaf, applying the NEDC (New European Driving Cycle) driving profile. The results showed a notable increase in energy consumption when in-car heating was applied. The range value obtained at 20 °C was 150 km, 85 km at 0 °C and 60 km at -15 °C (Lora et al., 2019).

Lie et al. (2020) also conducted a study on the energy consumption of electric vehicles based on the NEDC driving profile. Their findings indicated that energy consumption increased by 19.28% at high temperatures (30 °C) and by 67.3% at low temperatures (-7 °C) compared to average temperatures. (20 °C) (Lie et al., 2020). Hao et al. (2020) observed that electric vehicle energy consumption based on actual driving conditions was approximately 7% to 10% higher than that observed under NEDC driving profiles (Hao et al., 2020).

A number of factors have been identified in the literature on the energy consumption of electric vehicles as influencing this. These include vehicle weight, as discussed by (Burgess et al., 2003), and the use of air conditioning, as discussed by Kambly et al. 2014. Other factors relate to the driver, including driving habits, as discussed by (Wang et al., 2015) and driving behavior, as discussed by Tang et al., (2015). Finally, road conditions also have an impact, with factors such as the driving route, as discussed by (Lee et al., 2023), and road slope, as discussed by Liu et al., also being relevant. Traffic conditions (travel time, day or night driving) (Liu et al., 2016), traffic flow (Sun et al., 2015), traffic congestion (Greenwood et al., 2007), and the amount of regenerative braking (Qui et al., 2016), and the health status of the battery (Ozkurt et al., 2016; You et al., 2016 and Hu et al., 2015).

Conversely, the study on the margin of error in determining the state of charge (SoC) of the drive batteries asserts that the analysis of the impact of ambient temperature on energy consumption is also crucial for the optimization of electric vehicle performance and the provision of effective driving strategies to drivers (Liu et al., 2015). It is also stated that the difference in regenerative energy gain according to ambient temperature is one of the most significant factors affecting the energy consumption of electric vehicle drive batteries. It is hypothesized that thermal conditions influence the conductivity of materials within energy regeneration circuits, affecting the conversion of kinetic energy back into electrical energy. Furthermore, the energy gain is also subject to alterations in the physical properties of components, including resistance and capacitance, which are dependent on temperature. Consequently, it is proposed that the regenerative energy declines particularly in the context of low ambient temperatures. The greatest regenerative energy gain is observed within the average temperature range of 20°C to 30°C. One of the primary causes of elevated battery energy consumption during low-temperature driving is the diminished regenerative energy recovery observed at low ambient temperatures (Hwang et al., 2024).

The provision of accurate data on energy consumption and driving range in electric vehicles is considered to be of significant importance to alleviate customer concerns and encourage the widespread adoption of electric vehicles. This matches the findings of the aforementioned study, which states that changes in the energy consumption and range of electric vehicles under different weather and driving conditions are considered to be the main obstacle to their adoption by end users (Fetene et al., 2017). Consequently, it is argued that there is a pressing need for a more comprehensive understanding and measurement of the seasonal factors that influence energy consumption and range under real driving conditions.

The data set, which is based on the actual driving data of 197 electric vehicles of the same model recorded with 0.1 Hz frequencies for 12 months, has been used in the analyses to model the performance results of individual use, taxi operation, and car sharing for different purposes. The results demonstrate that the energy consumption of electric vehicles is subject to considerable variation according to the specific travel plans and charging processes employed, the intended use of the vehicle, and the prevailing seasonal conditions. It is therefore suggested that the electric vehicle concept, with a range of 160 km and an average charging interval of 1.6 days, is capable of satisfying the travel requirements of the majority of individuals. Nevertheless, for the utilization of the same electric vehicle model for car-sharing or taxi operations, more frequent charging processes are required due to the necessity for a considerably greater range. The unit energy consumptions obtained in these results are found to be 7% to 10% higher than the unit energy consumptions estimated by the NEDC test cycle (Hao et al., 2020).

Global sales of electric vehicles are on the rise, with projections indicating that approximately 17 million EVs will be sold by the end of 2024. This represents a notable increase from the previous year, with electric vehicles accounting for over one in five cars sold worldwide (BloombergNEF (June 26, 2024).

In China, the typical distance travelled by regular and constant weekday transport for commuting purposes is less than 30 km one-way. However, the annual mileage requirements of vehicles used for taxi businesses and car sharing concepts can reach 80,000 to 100,000 km (approximately 200-300 km/day) (Bauer et al.,2021). A similar situation is observed in the United States, where it is reported that taxis and car sharing require a daily range of over 200 miles, while less than 1% of personal use vehicles can reach these ranges (Moniot et al., 2019).

It can be reasonably concluded that the battery size and environmental impact of electric vehicles are influenced by a number of factors, including the determined usage concept, travel differences, weather, and driving conditions. These factors also influence end-user preferences, as they affect the unit energy consumption of electric vehicles.
The study introduces a novel metric, electric vehicle kilometers per (kWh × year), to assess the efficiency with which the total battery capacity of the Swedish passenger car fleet is utilized. The findings indicate that this metric varies between 166 and 208 electric vehicle kilometers per (kWh x year), contingent on the scenarios presented (Berg Mårtensson et al., 2024).

The study, which spanned an eight-month period, involved the collection of empirical data from eight battery electric passenger cars. The study considered the impact of various factors on energy consumption, including resistance forces, ambient temperature, the air conditioning system used, and energy consumption at idle. The study demonstrated that the resistance forces acting during driving exhibited a 5.4% decrease under high temperature conditions and a 13.3% increase under low temperature conditions in comparison to normal temperature conditions. It is also stated that energy consumption increases by 17.12% and 47.48% when the air conditioning system is activated in high and low temperature conditions, respectively, in comparison to when it is deactivated (Hu et al., 2023).

The energy consumption of air conditioning systems in electric vehicles has been calculated to account for approximately 33% of the vehicle's total energy consumption (Kim et al.,2010).

The findings of the study indicate that the heating function of the air conditioner has the potential to increase energy consumption by up to 50% when the outdoor temperature is extremely low (Kambly et al.,2015).

Also, studies have been conducted in which the internal conventional vehicles are comparatively examined with electric vehicles. The subject is addressed in a relatively straightforward manner, with a clear and concise approach.

In the study that compares the energy efficiency of internal combustion engine vehicles and electric motor vehicles, it is noted that the energy consumption of electric vehicles, when considering the electricity generated from coal combustion, is higher than that of diesel or biofuel-powered internal combustion engine vehicles. However, electric vehicles exhibit a higher torque index specific to mass (Gołębiewski et al., 2023).

It has been empirically demonstrated that the increase in vehicle size significantly contributes to higher non-exhaust emissions and energy consumption due to the associated increase in vehicle mass and driving resistance. For example, while Well-to-Wheel (WtW) CO_2 emissions from conventional vehicles double when comparing small cars to SUVs, the increment for Battery Electric Vehicles is somewhat smaller but still significant (Opetnik et al.,2024).

Carbon dioxide equivalent emissions (CO_2 e) escalate with increasing vehicle size; however, they can be mitigated by approximately 20% for conventional vehicles, and 17% for BEVs through eco-friendly driving practices. When emissions from vehicle production are included, BEVs exhibit on average approximately 50% lower CO_2 emissions compared to conventional vehicles. During an average 35 km journey , cold starts account for roughly half of the total NOx emissions from modern diesel vehicles, whereas for gasoline vehicles, cold start emissions constitute approximately 25% (Opetnik et al.,2024).

Furthermore, the selection of vehicle technology exerts a substantial impact on emissions. For instance, electric vehicles have a higher mass due to their batteries, requiring greater energy to propel them. This leads to increased tire wear emissions, although regenerative braking in electric vehicles significantly reduces brake wear particles. While electric vehicles do not produce exhaust gases from fuel combustion, the upstream CO_2 emissions from vehicle and electricity production anticipated in Europe by 2030 are expected to be approximately half of the average CO_2 emissions from Internal Combustion Engine vehicles, including the vehicle and fuel production (Opetnik et al.,2024).

The study encompassing the ecological comparison of electric and internal combustion engine vehicles throughout their entire life cycles, from mining to recycling, emphasizes the need to adjust current strategies and develop new measures for the advancement of electric vehicle production technologies keeping environmental risks in mind. To analyze the impact on environmental conditions, factors such as natural resource consumption, waste generation, electricity consumption, harmful substance emissions into the atmosphere, water consumption, and greenhouse gas emissions were considered. The comparison of the environmental impacts of the vehicles revealed that electric vehicles have six times higher natural resource consumption and industrial waste production compared to internal combustion engine vehicles (Kurkin et al.,2024).

It was determined that emissions of harmful substances and greenhouse gases from electric vehicle production are 1.65 and 1.5 times higher, respectively. During operation, electric vehicles exhibit higher energy consumption and release more harmful substances into the atmosphere, although they produce fewer greenhouse gas emissions. Ultimately, at various stages of the life cycle, electric vehicles have a substantially higher negative impact on the environment compared to gasoline-powered vehicles (Kurkin et al.,2024).

The scientific basis of the study lies in the establishment of a novel systematic approach to evaluate the potential environmental consequences of electric vehicles. The developed methodology provides a comprehensive performance assessment of the negative environmental impacts associated with the production of materials for electric vehicles. Additionally, it enables consideration of potential environmental risks when developing environmental marketing strategies, electric vehicle technology development programs, and resource and energy conservation programs (Kurkin et al.,2024).

In light of the related lecture notes from Massachusetts Institute of Technology, considering the Well-to-Wheel (WtW) efficiency parameter, it has been indicated that the overall efficiency of internal combustion engine vehicles is 13%, whereas the efficiency of electric vehicles is 23% (Topal, O., personal message, 2024).

A considerable number of countries are advocating the utilization of electric vehicles as a means of reducing carbon emissions. Nevertheless, it has been proposed that the battery charging process, which is inherently slower than traditional refueling, represents a significant obstacle to the widespread adoption of electric vehicles. Another study constructed a model to examine the concept, which included a charging station, a battery swap station, and a battery leasing company. It was intended to identify the optimal pricing strategy. The results suggest that the pricing strategy of the concept is contingent upon a number of factors, including the operating costs on the supply source, battery depreciation, battery capacity held in reserve, time lapses, and opportunity costs on the end-user side.

Furthermore, the study indicates that subscription strategies facilitate the initial market development of the battery swap concept. Subsequently, the more consumer-friendly pay-per-swap strategy is preferred (Hu et al., 2023).

4. CONCEPT OF THE LONG-TERM TEST AND THE DATA

This study presents a multi-dimensional comparison of 135 C-segment gasoline sedans and 75 C-segment electric compact SUVs of a corporate company operating in Ankara, Turkiye. The company has set a net zero emissions target for 2050 in its strategic roadmap. The main purpose of this study is to provide a comprehensive analysis of the total cost of ownership of these vehicles used in the company's urban transport operations, based on actual operational data collected over a 10-month period from June 2023 to January 2024.

The company's vehicles are based at three main sites and are operated in a similar way, with fast and slow charging stations installed at the same sites. Electric vehicles will be used within their existing battery capacity without prior specification, and no alternative approach will be taken in favour of electric vehicles. The charging process, which typically takes place after business hours, is limited to a maximum of 80% battery capacity for electric vehicles. This approach is designed to mitigate the effects of ageing on the batteries used to power the vehicle's powertrain. A total of six 120 kW DC fast charging stations with two plugs and 20 AC slow charging stations (3.5 kW) will be available for electric vehicles on the three campuses. This paper, which represents a significant sample of urban use in Ankara, Turkey, seeks to address concerns about the use of electric vehicles, particularly by businesses. The analyses, which also evaluate different financial procurement approaches such as purchase and leasing for electric and conventional vehicles, are intended to raise awareness of the decision-making mechanisms of public institutions and organizations.

The total monthly distance travelled by electric vehicles, which was the basis of the study, was determined using vehicle tracking systems integrated into the vehicles. The total amount of electrical energy consumed on campus has also been quantified through the use of filtering meters connected to the charging stations. This approach allowed to calculate the average base unit energy consumed at vehicle level for electric vehicles.

The internal combustion vehicles used by the company, which is another important aspect of the study, are refueled at petrol stations close to the sites. Similarly, for conventional vehicles, mileage data is provided through vehicle tracking systems, and the amount of fuel delivered can also be recorded at the vehicle level, allowing unit fuel consumption data to be reduced to the vehicle level for analyses. It has been reported that these vehicles are also being used to meet the needs of intercity transport.

Detailed technical specifications of the electric and internal combustion engine vehicles used in the study are shown in Table 1 below.

The real-time operational data, which are the focus of the study, are detailed in Table 2. In particular, the performance results for summer and winter climatic conditions, where the results are of interest, cover an 8-month period between June 2023 and January 2024. In total, on 3 different campuses where these vehicles are being used, the total monthly mileage and the energy/fuel consumption are given on a per vehicle basis. Consequently, MG is used for electric vehicles and SC for conventional vehicles. Table 2 shows the data collected on campuses and vehicle basis. It details the number and type of vehicles on a monthly basis, and the range energy/fuel consumption.

Table 3 shows the efficiency of the vehicle concepts on a monthly basis. It is assumed that the differences in campus location and user driving profiles have an impact on the vehicle concepts, where different efficiencies are calculated despite the same make and model of vehicle concept. For example, the highest and lowest efficiencies for electric vehicles were recorded in June and January, with 0.17 kWh/km and 0.46 kWh/km respectively. Similarly, 0.06 lt/km and 0.09 lt/km were calculated as the lowest and highest efficiencies for combustion engine vehicles in different periods. The change in energy consumption per km for vehicle concepts in different time periods was calculated to be 58% for electric vehicles and 50% for combustion engine vehicles. In addition, when evaluated in terms of average unit energy consumption in the summer/winter period, the energy consumption per km for electric vehicles increased by 38%, while the unit energy consumption for combustion engine vehicles decreased by 10%.

Table 1. Technical Specifications of Electric and Internal Combustion Engine Vehicles

Parameter	Electric Vehicle	Internal Combustion Engine Vehicle
		
Model Year	2024	2024
Model	MG ZS EV	Skoda Octavia 1.0 TSI E-Tec 110 PS DSG Elite
Vehicle Type	B Segment Kompakt SUV	C Segment Sedan
Motor Type	Electric	Internal Combustion Engine
Motor Power	114 kW (156 HP)	110 HP
Battery Capacity	72,6 kWh	--
Fuel Tank	--	47,8 lt
HVAC	Electric (Without Heat Pump)	Standard
Range	440 km (WLTP- Combined)	>1000 km (mixed fuel consumption)
MaxSpeed / Torque	175 km/h – 280 Nm	208 km/h – 200 Nm
Charging Time	DC 76 kW / AC 7 kW (DC % 20- % 80, 40 min.)	N/A
Transmission Type	Automatic	Automatic
Weight	1620 kg	1341 kg
Dimensions (LxWxH)	(4323x1809x1649) mm	(4689x1829x1486) mm
Storage Capacity	448 lt	600 lt

Table 2. Campus and Vehicle-Specific Test Data

		Campus _M		Campus _G		Campus _A	
		MG	SC	MG	SC	MG	SC
Period	Quantity	35	34	20	65	20	36
Jun-23	Distance Traveled	60,340	110,439	71,154	120,055	67,734	60,969
	Per Vehicle /km-month (Kilometer per Month)	1,724	3,248	3,558	1,847	3,387	1,694
	Consumption Fuel(liters)/Energy(kWh)	10,403.00	7,159.21	15,603.32	9,864.12	14,186.53	3,851.38
Jul-23	Distance Traveled	70,300.00	120,468.10	61,750.00	160,077.00	69,437.00	116,900.00
	Per Vehicle /km-month (Kilometer per Month)	2,009	3,543	3,088	2,463	3,472	3,247
	Consumption Fuel(liters)/Energy(kWh)	14,188.54	8,558.92	14,576.27	13,833.67	14,342.54	8,267.14
Aug-23	Distance Traveled	70,985.00	88,574.00	54,615.00	302,822.00	68,790.00	156,094.00
	Per Vehicle /km-month (Kilometer per Month)	2,028	2,605	2,731	4,659	3,440	4,336
	Consumption Fuel(liters)/Energy(kWh)	14,444.63	6,726.25	14,903.30	20,341.09	15,970.90	9,716.41
Sep-23	Distance Traveled	69,639.00	109,777.00	56,292.00	318,368.00	75,484.00	180,275.00
	Per Vehicle /km-month (Kilometer per Month)	1,990	3,229	2,815	4,898	3,774	5,008
	Consumption Fuel(liters)/Energy(kWh)	13,680.76	7,722.05	10,946.86	21,069.19	16,406.30	11,237.28
Oct-23	Distance Traveled	76,751.00	126,636.00	63,826.00	322,384.00	70,463.00	188,784.00
	Per Vehicle /km-month (Kilometer per Month)	2,193	3,725	3,191	4,960	3,523	5,244
	Consumption Fuel(liters)/Energy(kWh)	15,974.53	8,404.04	18,152.93	21,863.39	16.055,22	11,409.18
Nov-23	Distance Traveled	77,837.00	115,419.20	55,844.00	349,149.00	79,294.00	189,571.00
	Per Vehicle /km-month (Kilometer per Month)	2,224	3,395	2,792	5,372	3,965	5,266
	Consumption Fuel(liters)/Energy(kWh)	18,027.57	7,634.63	20,385.19	22,475.62	18,490.15	11,614.73
Dec-23	Distance Traveled	87,381.00	120,327.00	65,221.00	367,649.00	70,290.00	167,836.00
	Per Vehicle /km-month (Kilometer per Month)	2,497	3,539	3,261	5,656	3,515	4,662
	Consumption Fuel(liters)/Energy(kWh)	20,924.18	7,928.48	21,738.22	24,658.91	18,892.88	10,266.15
Jan-23	Distance Traveled	70,352.00	116,848.60	43,578.00	330,601.00	71,011.00	175,175.00
	Per Vehicle /km-month (Kilometer per Month)	2,010	3,437	2,179	5,086	3,551	4,866
	Consumption Fuel(liters)/Energy(kWh)	19,458.31	7,682.01	20,191.30	21,094.34	19,776.16	11,012.65

Table 3. Average Efficiency Values Based on Campus Deployment of Electric and Internal Combustion Vehicles

Efficiency (kWh-lt/km)	Campus_M MG	Campus_G MG	Campus_A MG	Campus_M SC	Campus_G SC	Campus_A SC
Jun.23	0,17	0,22	0,21	0,06	0,08	0,06
Jul.23	0,20	0,24	0,21	0,07	0,09	0,07
Aug.23	0,20	0,27	0,23	0,08	0,07	0,06
Sep.23	0,20	0,19	0,22	0,07	0,07	0,06
Oct.23	0,21	0,28	0,23	0,07	0,07	0,06
Nov.23	0,23	0,37	0,23	0,07	0,06	0,06
Dec.23	0,24	0,33	0,27	0,07	0,07	0,06
Jan.24	0,28	0,46	0,28	0,07	0,06	0,06

The detailed data in Table 4 are based on the fact that the electric vehicle concept does not use heat pumps, and that the waste heat from internal combustion engine vehicles can be used for air conditioning, especially during the winter.

Table 4. Energy Consumption Change per Unit between Summer and Winter Periods

Seasonal Change	SUMMER Jun-Jul-Aug		SUMMER Jun-Jul-Aug		SUMMER Jun-Jul-Aug	
MG	2.826,08	0,22	2.888,05	0,30	38%	increase
SC	3.071,31	0,07	4.586,47	0,06	10%	decrease

In the long-term tests, it was calculated that the electric vehicles used for company transport travelled an average of 2.875,13 km per month during the 8-month period of summer and winter, while the combustion engine vehicles travelled 3.999,40 km. It was found that the main difference for electric vehicles, which were used around 39% less, was the use of internal combustion engine vehicles in these intercity transport services. During the test period, the total mileage of electric and internal combustion vehicles is shown in Table 5 on a monthly basis.

Table 5. Average Distance Traveled per Vehicle per Month

Period	MG	SC
Jun.23	2.889,47	2.262,93
Jul.23	2.855,97	3.084,37
Aug.23	2.732,80	3.866,62
Sep.23	2.859,50	4.378,11
Oct.23	2.969,11	4.642,78
Nov.23	2.993,60	4.677,36
Dec.23	3.090,72	4.619,09
Jan.24	2.579,84	4.462,95

Table 6. Comparison of Unit Fuel / Energy Costs

	Average		Unit Cost*
MG	0,25	kWh/km	0,021+
SC	0,08	lt/km	0,097++

*June 1, 2024, the selling rate of Euro by the Central Bank of the Republic of Turkey is 34.89 TL.
+The unit price of electricity supplied by the corporate company for the study is 2.96 TL in June 2024.
++The unit price (including VAT) is 42.35 TL gasoline in Çankaya, Ankara on June 1, 2024.

Also, it is stated that CO_2 emission values are determined by WLTP (Worldwide Harmonised Test Procedure for Light Vehicles). Nevertheless, it should be noted that the relevant values may vary according to characteristics such as driver, driving style, and natural conditions (road, weather conditions, etc.). In this context, the CO_2 emission value for the internal combustion engine vehicle concept, as determined by the relevant catalogue values, is 116-119 (g/km) (Skoda, 2024). The calculations indicate that the use of electric vehicles owned by the enterprise prevented 208.73 tons of CO_2 emissions per year, while 520.38 tons of CO_2 emissions were caused by the conventional vehicles used. Overall, 311.65 tons of CO_2 emissions were emitted.

Based on the unit energy/fuel consumption of the vehicle concept over the entire test period, it was calculated that the electric vehicle achieved a 78% saving in unit fuel/energy costs compared to the internal combustion engine vehicle. These data are shown in the following Table 6.

Further, other fixed and variable costs based on the use of these vehicles are included. Accordingly, the study, which considered two different procurement approaches, performed financial analyses based on the conditions where the vehicles are leased and fully purchased in accordance with the general approach. Accordingly, an investment of EUR 159.419,50 for the installation of additional charging points specifically for electric vehicles and an additional labor costs of 1,5 man/month for the daily charging process at a total of 3 sites were included in the calculations. In the study, the unit costs obtained using the average exchange rate for the period, based on the 3-month period in which the company procured the vehicles in question, were used in the analyses. It is calculated that the electric vehicle concept has 30.86% higher purchase costs, and 37% higher leasing costs (1+1 -year contract) on a euro basis over the period considered. Other fixed and variable annual costs include periodic maintenance and repair costs, road tax, car insurance, and tires (winter tires and replacement), as shown in Table 7 below.

The unit costs of fuel/energy, maintenance and repair, and other fixed costs calculated on the basis of the total distance travelled and fuel/energy consumed by 135 internal combustion engine vehicles and 75 electric vehicles used by the company during the 8-month operating period are shown in Table 8. Accordingly, the data under the heading "Other Costs", which differ from the values for internal combustion engine vehicles, include the additional labor costs required for charging processes specific to electric vehicles, and the investment costs for the installation of charging stations. In particular, the investment costs required for the installation of charging stations are reduced to the total number of vehicles served at the vehicle level.

Table 8. Costs of Vehicle Concepts

Total Distance Traveled All Vehicle	Number of Vehicles	Energy / Fuel Unit Costs	Maintenance & Repair Unit Cost	Other Costs
SC 4.447.688,69	135	1,21	0,32	2.578,88
MG 1.783.990,00	75	0,09	0,17	162.783,70

Table 7. Costs based on Vehicle Concepts Used in Analyses

Annual (Euro)	Purchase Cost	Total Distance Traveled per vehicle for Maintenance Cost	Annual Maintenance Cost	M T V (Motor Vehicle Tax)	Comprehensive and Traffic Insurance Cost	Tire Cost (Replacement and Storage)	Rental Cost	Additional Personnel Cost (1.5 person-month)
SC	58.610,75	47.991	1.074,37	98,60	988,88	435,81	16.473,29	--
MG	76.697,67	34.657	306,98	131,49	988,88	423,72	26.120,93	1.820,11

5. FINANCIAL ANALYSES

Lastly, financial analyses were performed based on 3 basic approaches. Model I, where vehicles based on both concepts are leased, and Model II, where vehicles based on both concepts are purchased, are the main evaluation criteria. Reasons such as the "uncertainties" considered by the company to which the study refers, in particular for the initial transition to the use of electric vehicles, and the fact that the domestic electric car TOGG in Turkiye has not yet reached market maturity in terms of sales, have led to a preference for a different procurement approach.

The transition to a purchase rather than lease model for service vehicles, which is the main motivation of the company behind the study, started with combustion engine vehicles. It has been decided that a similar procurement model should also be applied to electric vehicles. However, due to immature market conditions in the leasing companies where the vehicles will be delivered, and the fact that the TOGG brand of electric vehicles that will ultimately be used has not yet been sold (in September-October 2023 period), a short-term lease with another brand of electric vehicles has been used. Thus, Model III has been proposed and financial analyses have been added to the study with an alternative approach where combustion engine vehicles are purchased and electric vehicles are used through short-term leasing.

In this context, the results of the analyses of the procurement approaches based on these 3 different models that can be used for company transport services are shared. Figure 1 shows the details of the 3 models.
Upon analysis of the data collected under real-world conditions

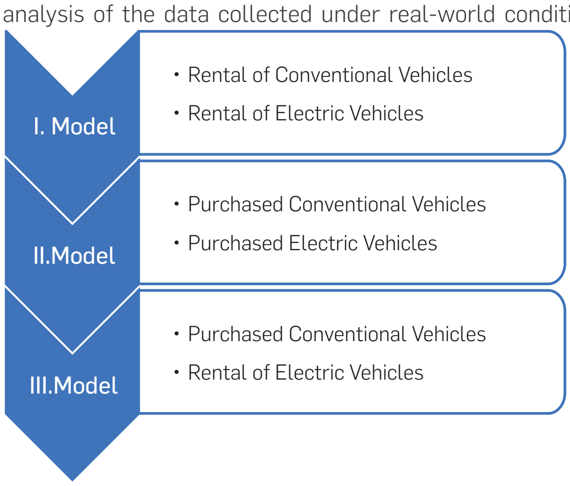

Figure 1. Financial Models Used in the Analysis

for combustion engine vehicles and electric vehicles, it became evident that the number of kilometers traveled by combustion engine vehicles is 28% higher than that of electric vehicles. This may be attributed to the limitations of recharging (range), or to the preference for the utilization of internal combustion engine vehicles in intercity transportation.

The results of the analysis according to Model I, which is based on the purchase of both vehicle concepts, demonstrate a cost advantage of 31% in favor of the internal combustion engine vehicle in terms of initial purchase costs on a vehicle basis. The financial advantage of the electric vehicle in terms of total maintenance and repair costs and fuel/energy costs on a vehicle basis is 60% and 82%, respectively, when a total period of 36 months is taken as the reference period.

In contrast, the calculations for the use of electric vehicles include a significant additional cost under the heading of other costs. This is in the form of additional labor requirements for the installation of charging points and the recharging process. In accordance with the correlation of the associated costs for 75 electric vehicles, the final result is a cost advantage of 13% in favor of internal combustion vehicles over the three-year period. Although the investment in recharging stations, which represents a significant cost item, can be incorporated into the calculations in various ways, in this study it is included under the most basic and cost-ineffective conditions. This is because the objective is to identify the most unfavourable scenarios regarding the use of electric vehicles and to dispel concerns.

The approach outlined in Model II, which advocates for the leasing of both vehicle concepts as a standard practice, reveals a cost differential of 59% per vehicle for electric vehicles. The unit prices used are the supply costs of the reference company for the pertinent periods, and are based on the 1+1-year contract that was duly executed. In addition to the leasing conditions, which are suboptimal for both the leasing company and the lessor, due to the aforementioned reasons, the limited car market conditions in Turkiye during the period when the vehicles were procured also contribute to the price differences that arise.

Finally, Model III, which is included in the study, represents the actual application approach that is supported by one-to-one real business data and the procurement approach offered by the company. The study is based on the fact that during the period when the vehicles were procured, the market saturation of the domestic electric car in Turkiye had not yet been reached. Given the supply shortage in vehicle supply, it was decided to take short-term rental services with different brands of electric vehicles (other than TOGG). Conversely, vehicles with internal combustion engines were purchased.

Compared to the other two methods, the outcomes of this approach, which do not permit an effective comparison, were also evaluated over a 36-month period. The findings of the study demonstrate that the three-year rental cost of electric vehicles is 34% higher (per vehicle) than the purchase cost of combustion engine vehicles. Moreover, despite the additional labor costs associated with the infrastructure and operation of the additional charging stations, only 11% of the total costs are calculated as additional costs for electric vehicles.

A noteworthy aspect of the company's electric vehicle (EV) charging operations is that the vehicles are charged regardless of the time during the day. This is because the vehicles are typically recharged immediately upon returning from work. It is presumed that the proposed charging concept, which is based on the principle of calculating the unit price of electricity at a lower unit price, considering the multi-time tariff, will result in significant benefits. A calculation has been performed to determine the feasibility of meeting the charging requirements of all vehicles in a sustainable manner. The results indicate that with the installation of 2 charging stations (with four plugs) with 120 kW charging power in Campus_M and the utilization of 35 electric vehicles with 76 kW DC charging power; the charging power capacity and charging time can be met in the period corresponding to the night tariff (22:00-06:00) for 20%-80% daily charging (corresponding to 220-280 km per day).

In this context, it can be estimated that two to three vehicles can be charged at any time to have them available for potential emergencies. The outcomes of the three models are shown in Tables 9 and 10 below.

Table 9. Models and Costs Based on Financial Analyses

		Investment Costs	Annual Operating Costs (MTV + Tires + Comprehensive and Traffic Insurance	Labor Costs	Other Costs
Model I		Purchase			
Equity	SC	58,610.75	1,523.30	-	--
Equity	MG	76,697.67	1,544.09	1,820.11	159,419.52
Model II		Long-term Lease (36 months)			
Rental	SC	49,419.87	-		-
Rental	MG	78,362.79	-		
Model III		SC Purchase Vs MG Long-term Lease (36 months)			-
Equity	SC	58,610.75	1.523.30		-
Rental	MG	78,362.79	-	1,820.11	159,419.52

Table 10. Results of Financial Models Used in Analyses

Equity	SC	77,268.71	Equity Total (3 years)
Equity	MG	309,220.55	
Rental	SC	61,562.39	Lease Total (3 years)
Rental	MG	80,537.66	
Equity	SC	75,719.70	Lease vs. Equity
Rental	MG	305,788.02	Total (3 years)

6. EVALUATION AND CONCLUSION

This section presents the findings of the assessment and draws conclusions. It is predicted that the adoption of electric vehicles will have a significant impact on national and international energy policies and global climate goals. Furthermore, it is anticipated that the adoption of electric vehicles will result in reduced energy consumption costs for individuals and organizations.

This study, which is based on a corporate company's long-term use of electric and conventional vehicles and supported by financial analysis based on real data, aims to shed light on the uncertainties and concerns of the relevant target audiences regarding electric vehicles. These vehicles stand out given their environmentally friendly nature, low operating costs, and operational efficiency. The study also seeks to provide effective evaluation and detailed information for decision-making mechanisms. The study offers a comprehensive examination of the total cost of ownership, with a view to assessing the utilization and leasing of electric vehicles by companies as a potential replacement for vehicles powered by internal combustion engines. The results of the analysis indicate that electric vehicles are more expensive than internal combustion engine vehicles, with a price premium of 11% to 13% inclusive of additional infrastructure costs. Nevertheless, the advantages of electric vehicles in terms of energy efficiency, low maintenance and operating costs, and environmental sustainability, indicate that this technology has the potential to drive significant change in the future. Furthermore, the implementation of electric vehicles has resulted in a reduction of 208.73 tons of CO_2 emissions per year, based on the assumption that 35 vehicles of this company are in operation.

In the long term, the adoption of electric vehicles is anticipated to confer strategic advantages and added value to companies. In line with corporate sustainability objectives and environmental accountability, the adoption of electric vehicles is considered a strategic investment. In this context, the environmental and economic benefits of electric vehicles are acknowledged as crucial elements that should be integrated into corporate strategies, offering substantial added value for global emission targets.

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