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Driving Forward: A Decade of Electric Vehicles Progress and Challenges in Jordan

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Abstract

The rapid transformation from conventional vehicles to electric vehicles (EVs) holds promise for enhancing air quality, reducing CO_2 emissions, revitalizing the renewable energy market, and enhancing countries' economies. This study investigated the performance of EVs in Jordan and the key challenges hindering their rapid development. It implemented a structured questionnaire of 202 EV owners/drivers and 15 interviews with technicians at many service centers. Findings revealed that Jordan leads among MENA countries in Battery Electric Vehicles(BEVs) market share and growth rate, with 52% market share of BEVs new cars in 2023, projected to surpass 80% by 2025. This rapid development is tied up with many internal and external influences; government backing, high fossil fuel prices, and tax exemptions are common causes that enhanced the market of EVs. Respondents highlighted prevalent issues of BEVs, including the rapid battery depletion, low battery capacity, electric inverter malfunctions, battery overheating, low performance in hot and cold climates, and inflating costs. Finally, this study recommends educational institutions to offer targeted training programs for EV maintenance and service, and the government should provide more incentives for this industry, and combat the influx of counterfeit charging accessories, batteries, and spare parts.

Keywords: Transportation Sector; Li-Ion Batteries; Hybrid Electric Vehicles; Air Quality; CO_2 emissions.

List of Abbreviations

Abbreviation	Definition
BEVs	Battery Electric Vehicles
EVs	Electric Vehicles
GCC	Gulf countries council
GEMRIX	Global Electric Mobility Readiness Index
HEIs	Higher Education Institutions
ICE	Internal Combustion Engines
LIBs	Lithium-Ion Batteries
MENA	Middle East & North Africa
PHEVs	Plugged-in Hybrid Electric Vehicles
RE	Renewable Energy
SoH	State of Health

1. Introduction

The transportation sector significantly drives national economies but also constitutes a primary contributor to air pollution due to vehicle emissions and their related industries, accounting for over one-quarter of global greenhouse gas emissions [1-3]. Addressing this global dilemma demands immediate policy action and proactive development of new technologies independent of fossil fuels [4]. Electric vehicles (EVs) have been a dream of scientists for more than a century. Despite numerous efforts for many decades to reduce the dominance of conventional fuel-based vehicles, the commercialization of EVs has been impeded due to low battery energy density [5]. However, the breakthrough of lithium-ion batteries (LIBs) revolutionized the technology of EVs, enabling their modern commercialization with superior performance attributes like high energy density, high reliability, low operating costs, and longevity [6].

The rapid development of the EV industry has resulted in a tangible financial return, low breakdown failure, high performance, and a high satisfaction rate. Nowadays, EVs is becoming a promising industry witnessing rapid global competition owing to their direct interaction with nations' economies, air quality, and revitalizing the RE market [7,8]. The EV industry provides a reliable link towards carbon neutrality and eliminating climatic change [9].

The world is witnessing rapid transformation of transport vehicles from conventional to electric, plausibly due to multiple merits. It improves air quality and reduces CO_2 emissions, especially in large and industrial cities. Furthermore, it is expected that EVs could enhance the control of the electricity supply-load curve of countries and boost the utility rate of intermittent-based RE resources,

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such as wind and solar energy resources. Unlike ICE cars [10-12] and hybrid cars [13,14], the running and maintenance costs of EVs are greatly reduced [15,16]. Besides, EVs are considered a plausible solution to the continuous headache raised by the electricity management of the daily and seasonal supply-demand curve fluctuations. Countries lose hundreds of megawatts daily during off-peak periods, with current recovery methods being both costly and inefficient in energy conversion. The widespread use of EVs could increase the maximum load that should be supplied to the electricity grid and enhance the share of RE resources. However, encouraging EV owners through discount initiatives to charge their car batteries during off-peak periods could significantly alleviate electricity supply-demand challenges.

Batteries have emerged as critical components for the sustainability of both the energy and transportation sectors, offering the promise of replacing internal combustion engine (ICE) vehicles. Lithium-ion batteries (LIBs) stand at the forefront of the EV industry, serving as essential components with high energy density and minimal self-discharge rates. LIBs represent more than 50% of the EV cost with high storage efficiencies and long-life cycles [17,18]. The use of LIBs for EVs has many advantages other than traditional batteries [19]; New versions of LIBs are being developed as solid-state batteries with solid electrolytes, although they are still in the early stages of commercialization. Furthermore, LIBs provide minimum self-discharge, rapid charging, high capacities, high energy densities, cost-effectiveness, long-life cycles, and low maintenance costs. Moreover, they can be recycled or exposed to second-life cycle applications, such as storing large-scale solar energy capacities [20].

A study conducted for 29 European countries from 2010 through 2020 investigated the energy conservation and environmental impact of BEVs. The outcomes indicated that EVs steadily reduce energy consumption and are more energy-efficient than conventional vehicles [21]. It was recorded that the process of transition of the transportation sector to EVs is the number one most significant contributor to eliminate greenhouse effect and CO_2 emission. A surge increase in the number of EVs in Europe countries; sales have increased from few thousands in 2010 to about 3.2 million registered EVs in 2023 [21]. Future aspects of EV batteries should be directed towards energy-saving and cost-effective processing, conservation of precious and preserved resources, environment safety control, life cycle assessment, and enhancing production efficiencies [19].

1.1. EVs challenges and barriers

The world is now witnessing a transitional stage from conventional vehicles to EVs. This shift has not been without challenges. The rapidly evolving EV industry has faced numerous obstacles that hindered its growth at various stages. Most of these obstacles relate to storage batteries, including challenges in manufacturing technologies, raw materials availability, energy storage density, life cycles, cost evaluation, and operating conditions.

Integrating LIBs to EVs has revolutionized the transportation system. Techno-economic studies suggest that the cost of EV batteries should be $ 80 - 130 USD/ 1 kWh to become competitive with ICE vehicles [17]. Recent threatening reports indicated that the price of LIBs has increased from $137/kWh in 2021 to $151/kWh in 2022 and is constantly continuing to increase every year. That is plausibly due to the surge increases in raw material costs [17]. LIBs in EVs have negligible emissions but their manufacturing processes export large amounts of CO_2 [21].Mainly, mining processes of raw materials emit large volumes of pollutants. The life cycle of EV batteries ranges between 5 to 8 years after almost 70% to 80% decay [18]. The retired EV batteries are expected to become a hurdle environmental issue that expected to reach about 7 million tons by 2030 if not recycled or disposed of [22].

One of the biggest challenges to the EV industry is the raw materials shortage used in batteries and motors. An EV and its motor needs, on average, about 66.3 kg of graphite, 53.2 kg of copper, 39.9 kg of nickel, 24.5 kg of manganese, 13.3 kg of cobalt, and 8.9 kg of lithium [23]. The whole EV sector faces a lack of reserves and will have severe supply issues in the coming years. A total of 80 million tons of Li_2O are available worldwide as a source of lithium for LIB. Compared to a five-year average of about $14,500 per metric ton, lithium prices have risen by about 550% in a year due to the surge in EV demand [23].

The average cost of automotive battery packs, adjusted for inflation, decreased from almost US-$1,200 per kWh in 2010 to just US-$132 in 2022. The world witnessed 80% increase of EVs selling from 2021 to 2022, from 3.9 million in 2021 to 7 million cars in 2022 [23]; China contributes to 51% of EVs world production with 64% yearly growth [24]. Tesla contributes to about 13% of EV sales, followed by SAIC-GM-Wuling with 9.3%, China's BYD with 8.5%, and Germany's Volkswagen at 8.5% apiece [23].

The distribution of EV raw materials reserves is limited to a few countries. China is the world's leading country in EV production, marketing, and raw materials reserves [25]. China has more than 70% of Cobalt mining and the world's top producer of Lithium, Cobalt, and Graphite, while Chille is the leading country of copper mining [23-25]. All these metals are primary raw materials of EVs.

Copper is also an essential element for EVs. Each single EV requires ~ 60 kg, mainly for batteries, motors, and electronics. Currently, the supply of copper worldwide is larger than the demand, and experts expect that by 2030, the situation will be reversed, and an extensive demand for copper in numerous industries [23,26].

With the increasing demand for LIBs and the urgent need to increase their capacity, energy density, and cycle life, many technical challenges have emerged and are facing this pivotal industry [27]. Inaccurate diagnosis and prediction of battery health state is a critical issue of LIBs. With more charge-discharge cycles, a stepwise deterioration to the battery health is observed through a steep decline in battery capacity and an increase in internal resistance [27].

The state of health (SoH) can be determined by dividing the current actual maximum capacity by the standard capacity. International standards confirm that an 80% SoH is an obvious indication of the deterioration of the battery [27,28]. To emphasize, SoH prediction of lithium-ion batteries is a complicated process that cannot be measured by conventional technologies, such as sensors. Condensed studies were attempted to diagnose the SOH of LIBs. All studies agree that the battery's charging-discharging mechanism, system temperature, and high currents (discharge rates) required to meet high loads are the most crucial factors that shorten the span life of a lithium battery [27,29,30]. Different models are attempted to predict the SoH of LIBs, with error percentages less than 2.5% [27,29,31].

It was demonstrated that EV batteries have great potential for enhancing the electricity economy if they are repurposed to the stationary mass storage systems of solar and wind energy [7, 32,33]; it is technically proven that the performance of EV batteries less than 80% SoH is an indication of retirement in EVs. In some cases, however, retired EV batteries can be a good option for solar energy storage [7]. Other claims suggest that recycling EV batteries is a better selection than reusing raw materials, such as Lithium, Graphite, Copper, and Cobalt [23]. Studies of second-life operation for solar energy storage were built based on the 70% remaining capacity of EV batteries after eight years of working on EVs, with a good techno-economic feasibility was obtained [34,35].

1.2. EV Batteries' Performance at Hot and cold climates

One of the biggest problems associated with LIBs use in EVs is the noticeable decrease in battery performance in hot and cold climates. This challenging problem hindered the rapid spread of EVs in many markets. In this regard, interesting results were obtained from a relevant study [36], which indicated that energy consumption of EVs in hot weather increases by 20% compared to cold weather (at 10°C) [36, 37]. In another study which tested another type of EVs, the outcomes indicated that there is 15% increase in the energy consumption in hot weather than in cold weather [38]. Also, a study of empirical experiments indicated that the temperature of 23 °C is the best choice for EVs in term of energy consumption [39].

An empirical work conducted in Kuwait, a country in Arab Gulf countries with a hot weather most of the year; they made an empirical work to investigate the performance of EVs in hot climates [40]. The results were unique. They found that using EVs at temperatures above 45°C could increase energy consumption by almost 30%. The simulated curve indicated that the optimal operation conditions are set between 20 – 30°C, and the performance gets down in hot and cold weather. The problems of EV heating are not a concern of energy consumption only, it decreases battery life and increases battery self-discharge [36]. Studies displayed that LIBs suffer from self-discharge and capacity reduction at high temperatures and are exposed to overheating plausibly due to short circuits or high ambient temperatures [41].

The performance of EVs in cold weather is also well-studied in the literature. A recent study built a Monte Carlo-based probabilistic simulation to quantify the impact of cold weather in the UK [42]. The result of this study indicated that an additional energy of 9-12% is required in winter months for the same trips. The excess energy is consumed mainly for battery temperature regulation and air conditioning heating of the vehicle's cabin [43,44]. Furthermore, cold weather causes rapid degradation of LIBs and a reduction in the battery span life. Specifically, cold weather increases the internal resistance of batteries, causing plating on the anode of the lithium layer.

The mechanism of battery degradation is complex and requires more diagnosing [44]. When the temperature exceeds zero degrees Celsius, the internal resistance increases due to the impedance of lithium ions' diffusion from the battery anode. Furthermore, charge transfer kinetics slowed down, and electrolyte conductivity reduced at low-temperature conditions [41]. Also, self-discharge could be enhanced due to the electrolyte freezing at extremely low temperatures [45]. Moreover, a specific empirical study inferred that low-temperature operating of EVs decreases the span life of LIBs by 130-140 cycles only [46]. Finally, it was inferred that battery capacity decreases by 23% when ambient temperature decreases to -15 °C [41].

The low performance of BEVs in hot and cold climates has forced manufacturing agents to design a proper cooling-heating system to keep LIBs at 20 – 30 °C while in operation. There are many cooling systems for keeping batteries at the preferred operating temperatures. An air-cooling system requires three times more energy than a liquid cooling system for the same temperature difference, especially at high charging/discharging rates [47]. However, a liquid-cooling system is 40% heavier than air-cooling for the same temperature difference. LIBs should be sustained at about 15 - 35 °C, but they get heated up during operation in EVs and get a problem with cool weather during winter in many countries worldwide [44].

In general, the thermal management systems of LIBs could be classified into four types: air-cooled, liquid-cooled, phase change material-based, and thermo-electric-based systems [47]. Each of these systems has its merits and weaknesses. However, EV manufacturing companies rely on the first two systems due to their adequacy for Li-ion batteries pack thermal loads.

1.3. EVs Development in Middle Eastern Countries

Middle Eastern countries are not world-isolated. The EV market has begun to invade the transportation sector in Middle Eastern countries. However, the growth of this sector varies from one country to another. Several fundamental factors directly affect this growth: (1) the prices of fossil fuels in each country and their availability in the country, (2) the weather in the country, as countries of sweltering summers or cold winters, EVs face technical problems during operation and are not welcomed by society, (3) the area of the country, as in countries with large areas, people do not prefer to buy BEVs unable to transport with them easily between cities in light of the lack of fast charging stations on the highways, and (4) the administration system the country has and its orientation towards sustainable development.

The market share of EVs in GCC countries exhibits different behaviors, in which their market is affected by extremely hot weather and abundant and cheap fossil fuels [37,48]. A recent study conducted in Kuwait targeted 472 drivers. However, the targeted sample participants did not have EVs at the time of conducting the study, which makes their responses inaccurate and does not reflect the present conditions and prospects of EVs in Kuwait [49]. Furthermore, the number of EVs in the country is still modest, with only 250-300 BEVs by 2022 [40,50]. The outcome of this study suggested that about 40% of participants started seriously thinking of buying EVs (not replacing the current ICE vehicles) in the next three years if the government provided some incentives and the cost went below the cost of gasoline vehicles. The per capita share of greenhouse emissions, in Kuwait, is 32.5 tons of CO_2 annually, ranked the second highest worldwide, next to Qatar. Statistics displayed that vehicles in Kuwait are three times more than residents [50] A new study conducted in Kuwait indicated that the PHEV market share in 2023 is 2.7% [51]. Despite more studies conducted in Kuwait regarding EVs, all the above mentioned studies did not provide any data regarding the current progress of BEVs in Kuwait right now.

The progress of the EV market in Qatar is also like that of Kuwait [52]. Doha city is the twelfth most polluted city worldwide. As per the fuel price in Qatar, authors suggest that the operating cost of EVs is 5 to 6 times cheaper than ICE vehicles. They provide cost comparisons between EVs and ICE cars for different agents. The results showed that EVs have 1.5 – 2.0 times more purchasing prices than ICE vehicles. However, the maintenance costs of EVs are 12 times less than ICE vehicles. The number of imported EVs in Qatar by the end of 2023 is about 1080 units [52].It was revealed that EVs could reduce CO_2 emission with 12 kg CO_2 per 100 km driving, compared to ICE vehicles [53]. The survey's outcome indicated that 14% of Qatari drivers are planning to purchase EVs in the next five years. Qatar's vision for 2030 is to reach 10% of all vehicles to be EVs [54].

Saudi Arabia is not isolated from the world of EVs; the government targets 30% of EVs in 2030 in the capital city (Riyadh) [55,56]. Of course, the market of EVs in Saudi Arabia is a hot topic and well documented from its technical, economic, and social aspects. A modeling and simulation study implemented in Saudi Arabia suggested that an increase of 20% in EVs could increase the electricity demand by 3.4% [57]. Furthermore, a study by A. Almutairi, 2021 investigated the willingness of Saudi people to purchase EVs in the next few years [57]; the results of this study indicated that most drivers use less than 100 km trips per day, which indicates that a single battery charging is sufficient for their EVs for a few days. Besides, a recent study conducted in Saudi Arabia indicated that Islamic and societal values did not influence the market share of EVs, indicating that the low market share of EVs in the country is an economic issue and is tied to people's desires [58]. An economic feasibility study in GCC countries indicated that the annual cost of EVs is USD 550 more than ICE vehicles [59]. Overall, based on governmental statistics by 2023, more than 71200 PHEVs were imported into Saudi Arabia, but there are no statistics about BEVs in the country.

Finally, the market of BEVs in UAE is still modest and requires more infrastructure to assist drivers in decision-making towards BEV purchase [60]. A study conducted in UAE indicated that the functional private and societal values towards EV purchase positively affect females more than males. Furthermore, younger drivers have more tendency to purchase EVs than adult drivers [61]. This study expects that the rapid development of BEVs globally could allow them to penetrate the transportation markets of GCC countries in the coming few years.

1.4. EVs Performance in Jordan

For a decade, Jordan stormed the world of EVs as the first country in the MENA area, driven by the rise in conventional fuel costs and the lack of resources in the country [62-65]. Not only EVs markets, but Jordan is also the leading country in the Middle East regarding RE projects, especially wind and solar energy [66]. The country attempts to reduce dependence on imported fossil fuels [67-69]. Transportation is the most energy-intensive sector in Jordan, contributing to about 46% of the total energy consumed in the country [70]. They are a major source of CO_2 emission and air pollution, causing many long-term health issues [70,71]. Although tremendous research has been explored to examine the performance of EVs worldwide, very little research has examined this phenomenon in Jordan, especially from the viewpoint of maintenance centers, owners, drivers, and EV agents. There is an urgent need to recognize customer experience, feedback, and perceptions in dealing with EVs in Jordan and other countries. Undoubtedly, the rapid transition from conventional ICE vehicles in Jordan to BEVs could reduce CO_2 pollution to lower rates and enhance the RE market in the country.

As with any new product, EVs face many socio-economic challenges at the first step. Drivers were unwilling to purchase them, the absence of charging units, no government incentives, initial high cost, and the absence of after-sales services are examples of barriers to EV development. The government of Jordan facilitated these barriers and challenges step by step, exempted taxes, and provided charging facilities. More importantly, the Jordan Ministry of Electricity studied earlier the overall impact of EV fleets on the electricity demand and planned wisely [71].

According to the Global Electric Mobility Readiness Index (GEMRIX) 2023" report, Jordan is the only country in the MENA region with a 10% sales share of BEVs and PHEVs. Other countries in the region, such as UAE and Oman, have sales share of less than 3% from PHEVs only [72]. However, this report did not provide data for BEVs alone. It considered PHEVs amongst electric vehicles in the analysis.

Now, many calls to integrate BEVs and PHEVs in the technical, vocational, and university education courses and diplomas [70]. Based on her survey in Jordan HEIs, there are more than 7 vocational and university institutions planning to open diploma course in this topic [70]. Not only that, but public authorities in Jordan also decide to replace their ICE vehicles with EVs and put adequate budgets for such development since 2019 [65].

Despite the high market share of EVs in Jordan, studies about the technical performance, economic saving, and satisfaction are not reported in the literature. This study is an attempt to investigate the techno-economic performance of EVs in Jordan, their challenges, and prospects.

2. Methodology and Research Design

This study implemented a mixed Qualitative-Quantitative approach. A structured questionnaire was organized, evaluated, and distributed to the participants. The questionnaire asks for participants' demographic information and general data on EV manufacturers and imported agents. The body of the questionnaire was designed based on the 5-point Likert scale. Many questions were introduced to the respondents regarding the performance of EVs by owners and drivers. Additionally, questions regarding the most severe problems frequently occur for EVs in Jordan.

More than 25 questions were arranged in the questionnaire written by Google and distributed online through social media networks. The questionnaire was structured in Arabic and then translated into formal English for further analysis. All responses were filled out online, and no face-to-face distribution system was followed. A total of 202 responses were completed; 25% of respondents are owners of PHEVs, while the remaining 75% are BEV owners and drivers. The questions enquired about the performance of EVs, their commonly occurring failures, and their consequences. The financial problems and after-sales services problems are also investigated. Electrical faults and how they deal with them are also enquired. Governmental incentives in Jordan, mileage rate, and daily expenses on EVs are critical questions addressed in this study. Finally, questions about the satisfaction rate are recorded in the questionnaire.

Interviews were conducted with 15 maintenance workshop technicians. Well-prepared questions were asked of the technicians and engineers at EV service shops. Their responses provide profound answers to many common technical problems of EVs. Their responses were tabulated for further discussion in the next chapter. Problems of EV charging facilities and their impact on the rapid transformation to EVs were also discussed. Interviews are conducted in 11 service centers in Amman city and 4 service centers in Irbid city. Those service centers belong to many officially licensed manufacturing agents of EVs.

Problems of EVs that were already discussed in the literature were also gathered and discussed in this study. The performance of BEVs in hot and cold weather is also discussed based on previous studies and the responses of EV owners in Jordan through questionnaires and interviews. Data were statistically analyzed using SPSS software and the values of mean, standard deviation, variance, correlation factor, etc., are tabulated in tables and presented in the Results section.

Figure 1 presents the demographic information related to the questionnaire respondents. Specifically, **Figure 1(a)** shows that 97.4% of respondents are owners of BEVs or PHEVs, while the remaining percentage drives EVs based on rent contracts. Additionally, **Figure 1(b)** expresses that more than 91% use EVs for personal uses, and only 9% use them for commercial use. One critical data is obtained in **Figure 1(c),** which indicates that 75.4% of respondents have BEVs while 24.6% have PHEVs. Finally, **Figure 1(d)** presents the city-based distribution of respondents in Jordan. The results indicate that most respondents belong to Amman and Irbid cities of 59.2% and 23.4%, respectively. Except for Amman and Irbid, other cities have modest participants in the 1 – 4% range for each city, with a cumulative percentage of 17.2%. This demographic data could be used as variables in the statistical analysis.

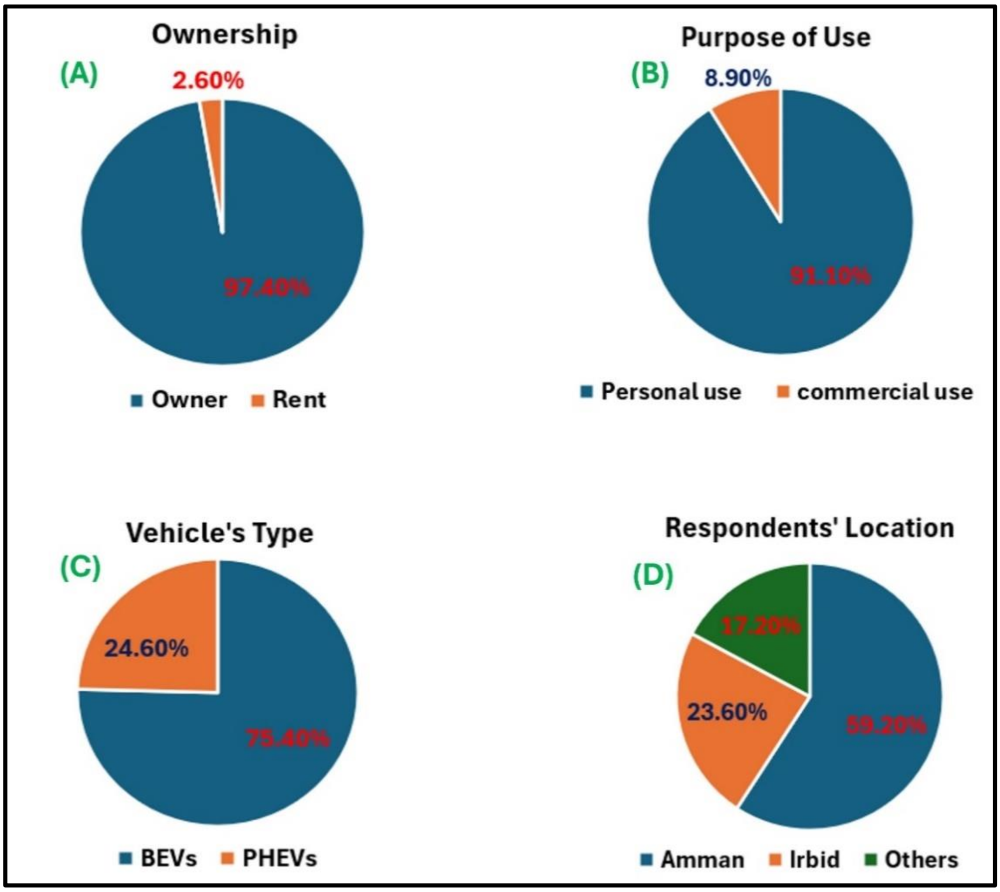

Figure1. Demographic and personal information of questionnaire respondents in 2024.

Figure 2 provides statistical data about the manufacturing year of each EV that is included in the questionnaire. The graph illustrates that the sample is well distributed amongst all studied periods. The manufacturing year is a critical variable in this study while investigating the performance of EVs in Jordan. The manufacturing company of EVs represents an important variable for studying their performance, which was considered in this study. However, the names of companies were exempted to avoid legal affairs.

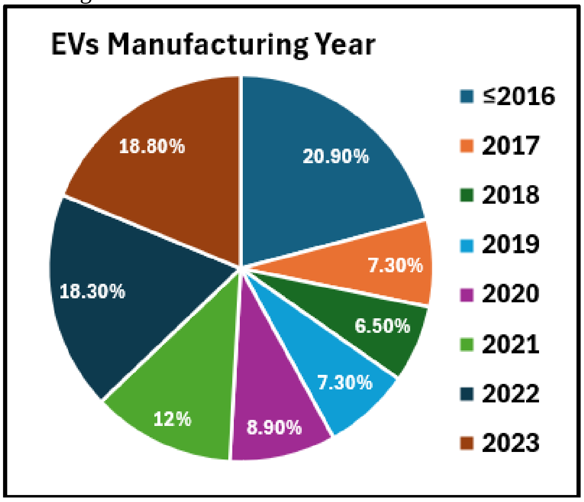

Figure 2. Distribution of EVs of respondents based on the manufacturing year.

This study provides several hypotheses that will be examined during the analysis. These hypotheses are:

- **H1.** Government incentives are essential for the rapid development of EVs.
- **H2.** Hot and cold weather greatly influences EVs' performance and energy consumption.
- **H3.** Manufacturing year and manufacturing company name greatly impact customer satisfaction.
- **H4.** Battery type and capacity greatly impact customer satisfaction.
- **H5.** Charging facilities of EVs greatly impact customer satisfaction and market share.
- **H6.** Cooling system type affects the performance of EVs.
- **H7.**The customer satisfaction rate is greatly and positively impacted due to the large decrease in the running cost of EVs.
- **H8.**The satisfaction rate of BEV owners is higher than those having PHEVs.

3. Results and Discussion

This section presents the results of the questionnaire and interviews conducted in this study. It offers a state-of-the-art market share, performance, economy, and satisfaction of EVs in Jordan. It provides a good discussion and comparison of this study with many similar studies in the literature review.

3.1. Annual Market share of EVs in Jordan

Figure 3 shows the flow of the EV market in Jordan from 2014 to 2024. The curve exhibits dramatic and irregular changes in the EV market. The first EV imported to Jordan was in 2014, with a total of 82 vehicles. It increased linearly through the next two years; it reached 253 EVs in 2015 and 797 EVs in 2016. The slow growth is explained in terms of social and economic barriers. In these three years, there were no governmental incentives and EV infrastructures required for charging, maintenance, and all after-sales services were not available.

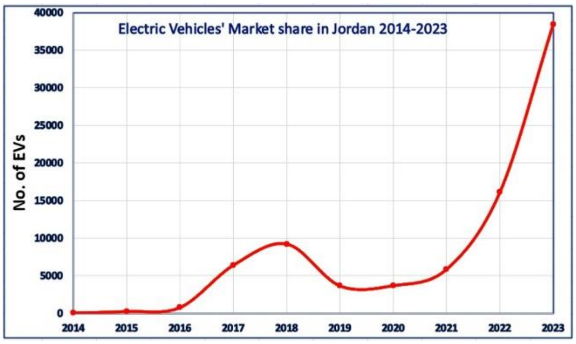

Figure 3. A plot illustrates the imported Battery EVs in Jordan during 2014 through 2023.

The curve behaves in another manner during 2016-2018, in which rapid increases in EVs imported to Jordan are observed. It has jumped to 6423 EVs in 2017 and 9228 EVs in 2018. Unusually, EV sales witnessed a sudden decline in 2019, plausibly due to the imposition of additional government taxes at the end of 2018. These new regulations caused a steep decline in EV sales in 2019 to 3,657 EVs [65].

Low sales of BEVs during 2020 and 2021 are attributed to the cessation of COVID-19, which is a common phenomenon in almost all countries worldwide. The Corona pandemic caused zero growth in EV sales in 2020 at 3691 EVs and slow increases to 5863 EVs in 2021. During this period, the Jordanian government issued a set of regulations in 2020 that provided incentives, tax exemptions, and charging infrastructures to BEVs; that was done to reduce dependence on imported fossil fuel and to reduce air pollution and CO_2 emissions rates in the country.

The government incentives and economic growth during 2022 and 2023 make the sale market of EVs firing, reaching unexpected rates, as shown in **Figure 3**. The number of EVs sold in 2022 increased almost twice to 16100 EVs. Similarly, 2023 witnessed rapid growth to reach 38400 EVs by the end of 2023. This prompt growth is expected to continue in the next few years, and Jordan is now the leading Middle Eastern country in terms of BEV sales and market share and is expected to continue in the future. The dramatic changes in market share in Jordan during 2014-2024 showed that government support is essential for BEV rapid growth, which agrees with the first hypothesis "***H1***" of this study.

Figure 4 explains the market share of BEVs in Jordan from another viewpoint. It points out that BEVs exhibited exponential growth in market share in the last three years. Exceptional outcomes elucidated that the market share of BEVs in Jordan is 52% amongst all other types of vehicles, which is a unique percentage in MENA countries. The histograms point out that the market share of Petrol, Diesel, and Hybrid vehicles has been witnessing a constant decline during the past few years. These findings suggest that the market share of BEVs in Jordan will exceed the 80% barrier among other vehicles after a couple of years.

Many countries in the MENA region, especially in GCC countries, expressed an increase in PHEVs [40,49,55]. However, none of these countries has a market share of BEVs, indicating that Jordan is the only country in the region with BEVs high annual market share rates.

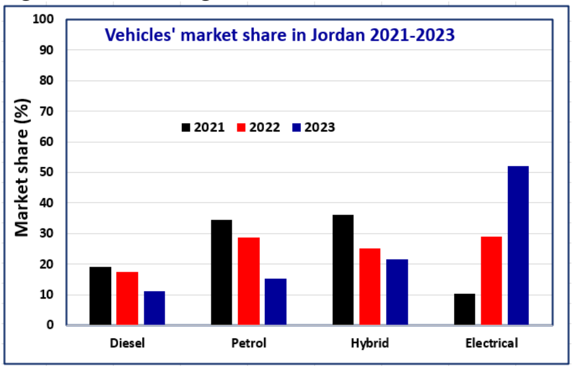

Figure 4. A histogram shows the market share percentages of Diesel, Petrol, PHEVs, and BEVs in Jordan during 2021-2023.

3.2. Satisfaction Rate of EVs in Jordan

Customer satisfaction rate is measured as a function of many variables, such as the type of battery, EV type, manufacturing company, daily driving distance, and daily charging cost. As depicted in **Figure 5**, The owners of Electric vehicles who employ Lithium batteries express high satisfaction with high priority to BYD Blade batteries at almost 90%, followed by ternary Li batteries (A battery manufactured from three metals along with lithium; these three metals are nickel, cobalt, and manganese). Since about one-fourth of respondents have hybrid EVs, an analysis of the satisfaction rate based on the type of EVs is essential; the satisfaction factor of BEV owners is 86%, while for PHEV owners 67.4%, as illustrated in **Figure 5**. The high percentage of satisfaction factor for BEV owners provides a satisfactory answer to the rising question: why the market share of BEVs is constantly increasing in Jordan while the PHEV market share is declining?

EV owners who use their vehicles for personal purposes and drive shorter distances daily, resulting in lower charging costs, tend to report higher satisfaction rates. These findings are well documented in **Figure 5**.

An interesting finding from the analysis of the questionnaire pointed out that an EV customer satisfaction rate is highly influenced by the manufacturing company name. In other words, customers' responses provided different satisfaction rates for different manufacturing companies. However, this study omitted the names of companies to avoid legal consequences.

Figure 6 elucidates that the owners/drivers of newly manufactured EVs showed higher satisfaction rates than relatively old ones. Specifically, customers of new EVs manufactured in 2022 and 2023 expressed high satisfaction rates above 90%. Unexpected results showed that EVs manufactured before 2017 voice relatively higher satisfaction rates, plausibly since most EVs at these periods are PHEVs. Anyway, the owners of PHEVs did not face the problems of charging and charging costs; thus, they provide slightly higher satisfaction rates at 75-78%.

The above discussion provided a clear picture of the root causes behind the high or low customer satisfaction rates among various types of EVs. It discussed many variables that may affect the satisfaction rate, such as EV type, battery type, nature of use, and daily expenditure.

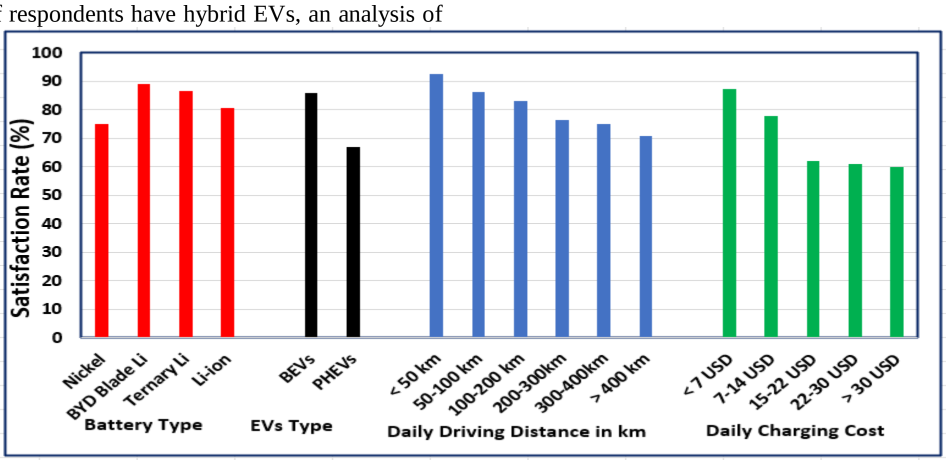

Figure 5. An illustration plot expresses the relationship between satisfaction rate and battery type, EVs type, driving distances, and daily charging costs.

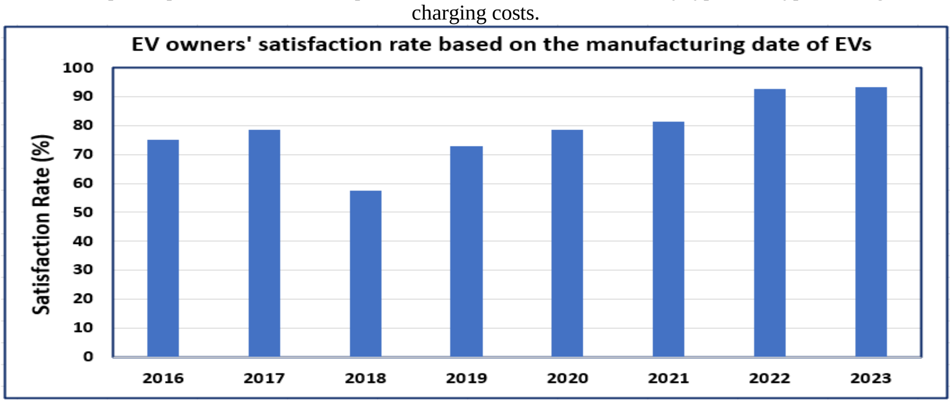

Figure 6. A histogram shows the relationship between Satisfaction rate and EVs manufacturing year.

3.3. The performance of EVs in Jordan

This subsection presents the results of the performance of EVs and the barriers to this new technology based on the questionnaire results and maintenance technicians' interviews. Many raised concerns about EV performance have been introduced and discussed based on the literature review.

Based on their experiences with EVs, Jordanian respondents provided their opinions about the intensity of many technical problems often associated with EVs. **Figure 7** provides graphs that summarize the responses to three common technical problems with EVs. Respondents pointed out that the battery's rapid degradation is a critical problem for EVs in Jordan. Furthermore, the battery heating problem is not prevalent in Jordan, plausibly due to the moderate weather of the country most of the year; respondents showed that battery heating is also a critical and common problem in EVs, but its solution should be sponsored by manufacturing companies and little to do from users to avoid this problem. Finally, respondents indicated that inverter problems in EVs are minor and new EVs have fewer problems with them.

Table 1 depicts the statistical data corresponding to questionnaire variables and owners'/drivers' opinions. It provides precise information on the sample size, range of selection, mean, standard deviation, variance, etc. Also, it introduces precious information about the respondents' opinions regarding many issues related to EVs in Jordan. The findings of **Table 1** are summarized into two categories and their intensities depend on the value of the mean (μ= mean); the first category describes the advantages of BEV use, which can be in terms of (1) providing good performance in terms of acceleration/ deceleration (μ=4.31), (2) low consumable parts and no machine lubricating oil (μ=4.25), (3) high reliability and safety (μ=4.05), and (4) low running costs with means of (μ=4.42). On the other hand, respondents summarize the techno-economic problems of BEVs in these points: (1) overpriced (μ=3.43), (2) battery degradation (μ=3.7), (3) performance decreases at overloads or inclined roads (μ=3.37), (4) lack of service centers (μ=3.82), (5) low number of public charging centers (μ=4.08), battery heating problems (μ=3.41).

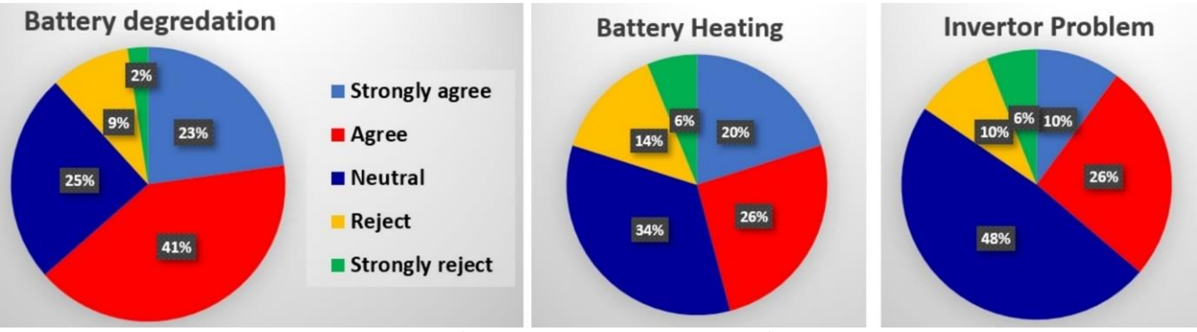

Figure 7.I llustration diagrams present the intensity of EVs technical problems in terms of battery degradation, battery heating, and invertors problems as per the Jordanian EVs drivers.

Table 1. Statistical data of research variables based on questionnaire responses. The data was recorded based on SPSS analysis and the sample size = 202.

	STATEMENT	Range	Mean (μ)	Std.Error	Std.Dev.	Var.
A	EVs Type (BEVs/HPEVs)	1.00 – 2.00	1.81	.028	.396	.157
B	Purpose of use (Personal/commercial)	1.00 – 2.00	1.1	.021	.299	.090
C	Owner/Rent	1.00 – 2.00	1.04	.014	.196	.038
D	Manufacturing Year	1.00 – 5.00	2.93	.095	1.353	1.830
E	Use period in Years	1.00 – 4.00	3.16	.067	.951	.904
F	Daily distance in km	1.00 – 5.00	2.46	.079	1.129	1.275
G	Battery Type	1.00 – 5.00	3.2	.079	1.124	1.264
H	Battery Capacity	0.00 – 5.00	2.65	.102	1.452	2.108
I	Charging Technology	1.00 – 3.00	2.04	.034	.481	.232
J	Charging Period	0.00 – 5.00	2.66	.091	1.287	1.657
K	Distance traveled per charge	0.00 – 5.00	2.98	.100	1.426	2.034
L	Daily expenditure	1.00 – 5.00	1.58	.065	.924	.854
M	Batteries heating is the most dangerous problem of EVs	1.00 – 5.00	3.41	.080	1.14	1.297
N	Low consumable spare parts and lubricating oil are advantages of EVs	1.00 – 5.00	4.25	.059	.831	.690
O	Most failures of EVs occur in Invertors	1.00 – 5.00	3.25	.067	.95	.900
P	The capacity of EVs Batteries reduces with time	1.00 – 5.00	3.7	.071	1.00	1.002
Q	Performance of EVs reduces at overloads and inclined roads	1.00 – 5.00	3.37	.089	1.254	1.572
R	Purchasing cost of EVs is overpriced	1.00 – 5.00	3.43	.077	1.091	1.190
S	The lack of service centers reduces EVs rapid development	1.00 – 5.00	3.82	.073	1.03	1.068
T	I believe that low no. of charging centers reduces EVs widespread	1.00 – 5.00	4.08	.067	.953	.908
U	EV market spread much in rental vehicles than personal use vehicles	1.00 – 5.00	3.25	.085	1.21	1.461
V	EVs show best performance for acceleration/ deceleration rate	1.00 – 5.00	4.31	.059	.84	.703
W	The performance of water cooled EVs is better than air-cooled system	1.00 – 5.00	3.79	.07	.99	.984
X	I believe that EVs are reliable and safe enough	1.00 – 5.00	4.05	.061	.865	.748
Y	Satisfaction Rate	1.00 – 5.00	4.18	.071	1.00	1.006

Table 2. Pearson's linear correlation factors of research variables, Sample size = 202 respondents. Values of *f* close to zero indicate a neutral relationship, large positive values indicate a positive correlation, and large negative values indicate negative correlations.

	STATEMENT	B	C	D	E	F	G	H	I	J	K	L	M	N	O
B	Purpose of use (personal/commercial)	1	0.358**	-.006	.023	.080	.048	.203**	.015	.056	.107	.035	.006	.115	-.110
C	Owner/Rent		1	-.029	-.028	-.102	-.142*	.120	-.081	.014	.245**	.014	-.086	.037	-.189**
D	EVs Type (BEVs/HPEVs)			1	-.092	.382**	.269**	.044	.332**	.273**	.359**	.565**	.485**	-.081	.278**
E	Manufacturing Company				1	-.346**	-.139*	-.003	-.387**	.097	.042	-.169*	-.132	.036	-.021
F	Manufacturing Year					1	.540**	.133	.510**	.374**	.097	.460**	.615**	-.039	.358**
G	Use period in Years						1	-.117	.333**	.261**	.201**	.240**	.436**	-.088	.235**
H	Daily distance in km							1	.053	.155*	.109	-.016	.097	.291**	-.009
I	Battery Type								1	.298**	.011	.232**	.456**	-.083	.259**
J	Battery Capacity									1	.229**	.227**	.575**	.041	.191**
K	Charging Technology										1	.281**	.313**	.149*	-.048
L	Charging Period											1	.583**	-.064	.391**
M	Distance traveled per charge												1	-.030	.438**
N	Daily expenditure													1	-.218**
O	Satisfaction Rate														1

Table 2 summarizes the correlation factors (*f*) based on Pearson's linear algorithm. The following results can be derived from the table.

1. There is a correlation between the purpose of use and the daily distance driven. Commercial users move larger distances using EVs than personal users (*f*=0.203).
2. Personal users show a higher satisfaction rate than commercial users (*f*=-0.11).
3. Most personal users are owners of EVs (*f*=0.358).
4. The type of EVs is an essential variable in the analysis. Most new EVs are BEVs, while most old EVs are PHEVs (*f*=0.382).
5. BEVs use more advanced batteries (*f*=0.332) with higher capacities (*f*=0.273), better charging technologies (*f*=0.359), and higher charging duration (*f*=0.565) than PHEVs.
6. Daily expenditure for BEVs is less costly than PHEVs (*f*=-0.088).
7. The owners/drivers of BEVs are more satisfied with their vehicles than PHEVs (*f*=0.278).
8. Each Manufacturing company has its characteristics of batteries, chargers, and manufacturing year, and its choice affects the satisfaction rate.
9. The column of manufacture year shows that it is a critical variable, indicating the rapid development of BEVs with time. The owners of newly manufactured BEVs showed an extremely high satisfaction rate than old vehicles (*f*=0.358).
10. New manufactured EVs have excellent charging properties (*f*=0.615), charging period (*f*=0.460), and battery capacity (*f*=0.374).
11. Those drivers/owners with long experience with EVs show high satisfaction rates (*f*=0.235), use advanced batteries (*f*=0.333) and charging technologies (*f*=0.201), and spend less money on their EVs (*f*=-0.088).
12. There is no correlation factor between the satisfaction rate and the daily distance driven by EVs (*f*=-0.009).
13. Charging technology used by the owners of EVs has a negligible effect on the satisfaction rate (*f*=-0.048).
14. Charging period(*f*=0.391) and distance traveled per charge (*f*=0.438) positively impact the satisfaction factor.
15. As the daily expenditure on EVs increases, the satisfaction rate decreases (*f*=-0.218).

3.4. Technicians Responses

Generally, owners and drivers of EVs could not provide precise answers to the technical problems of their vehicles. For that, this study implemented many interviews targeting engineers and technicians at EV service centers, with intension to investigate challenges and barriers that hinder their spread and development. Furthermore, these interviews provided precious information about the root causes of EV faults and their consequences on the performance of EVs. This expert segment was targeted because they are more familiar with the problems of electric vehicles and the challenges they face, based on their technical experience.

Regarding the problems associated with batteries of EVs, technicians reported that customers often face a challenge with replacing old batteries with new batteries.

The fast development of battery sciences and technologies made old batteries unable to be replaced with the same model due to the rapid enhancement in their capacities, safety enhancement, and charging capabilities. A critical problem frequently faced by the owners of EVs is battery capacity self-depletion and a reduction in efficiency, in which batteries, before reaching the life cycle, are unable to charge fully. Old EVs had an air-cooling system, which was insufficient for the hot summer climate. Also, old EVs did not constitute a heating system for batteries to perform well in cold weather. Of course, manufacturing companies have taken care of these issues, and hence, most new EVs now have a water-cooling system for cooling batteries during operation and a heating system during winter climates.

Technicians also indicated that the available rapid charging systems increase the battery temperature and promptly decrease its life span. In this regard, technicians recommend owners of BEVs to avoid using fast charging systems at least with the current specifications. Again, most EV owners in Jordan use home charging facilities; therefore, service technicians pointed out that most LIBs failures are due to using non-original chargers recommended by manufacturers. All in all, the technicians' interview analysis suggests that most charging problems associated with BEVs can be rooted in the lack of experience in installing charging points with the correct specifications or the use of traditional chargers that are not recommended by the manufacturers' specifications.

Despite the low moving parts and low maintenance requirements in the EVs, preventive maintenance procedures that the BEV owners/drivers should check periodically can be summarized in these points: testing the readiness of tires, gear oil, coolant, and brake systems and their fluids. One of the most important preventive measures is a routine and scheduled computer test to ensure that all BEV systems and sensors operate properly [73,74].

When the research team introduced a question regarding the performance of EVs in extremely cold or hot weather? Technicians' answers agreed with the context of this question. The mileage of BEVs in the winter climate is significantly reduced, plausibly due to the battery heating system. That is to maintain the appropriate operating battery temperature to ensure its operation in ideal conditions and extend its life. Furthermore, technicians pointed out that the mileage rate in hot weather also decreases, which is in line with other studies conducted in countries of hot summer weather, at temperatures above 45 °C [37,49]. In sweltering climates, the energy consumption significantly increases, and the mileage declines, plausibly due to the high energy required for air conditioning or liquid-cooling systems of LIBs. Finally, they also pointed out that the effect of hot and cold weather on EV performance is negligible in Jordan's climate.

Technicians indicated that BEVs are like other new ICE vehicles in terms of control panels and computer systems; BEVs display warning signs on the information screen, and the same sign may have more than one indication of faults. Therefore, in these cases, it is recommended to consult specialized centers to conduct a computer examination to diagnose the problem and attempt to resolve it.

The rapid development of BEVs and the intense competition between BEV manufacturers have increased the need for technical institutes to graduate technicians who are proficient in dealing with the EVs problems and can sustainably communicate with new technologies in this context.

All in all, due to the rapid development in the EVs industry, most technical problems in EVs are common and undertaken by manufacturing companies and are resolved in the new manufactured versions. There are other EV challenges, which depend mainly on the country's climate and government policies. In this regard, the market of EVs in Jordan is expected to develop rapidly in the coming years. That is plausibly due to (1) the extremely high operating costs of conventional vehicles, (2) the governmental support and incentives, (3) the low area of the country and the short distances between main cities, (4) the availability of after-sale services, and (5) the country climate is neither extremely hot nor cold.

This study proved that the market of EVs in Jordan has become of economic and social importance in Jordanian's daily life, which is not a common phenomenon in other countries in the region [75]. The government has constantly worked to overcome all the difficulties facing the EV market and is planning to include it in the vocational and higher education programs. Based on this surge increase of markets share of EVs in Jordan, studies indicated their negative impact on the electrical grid overloading due to batteries charging [71]. Experts estimated that about 80% of imported EVs are manufactured in China. Specifically, the most EV agents in Jordan contributed to the majority of market share are Tesla, Nissan, Hyundai, Fiat, and Volkswagen [71,75].

4. Conclusion and Recommendations

The performance and market share of EVs in Jordan have been investigated in this study. A structured questionnaire and interviews with technicians and specialists were employed as the primary methodological tools in this study.

Jordan shows the highest annual market share of BEVs in all MENA regions, with more than 52% by the end of 2023, on the account of petrol, diesel, and hybrid vehicles. The market of EVs in Jordan has been progressing for a decade, while many countries in the region have not started yet. The encouraging government measures changed the general mood of citizens positively, making them socially and technically accept this new transportation technology. Jordanians show a high satisfaction rate with the use of EVs at 86% for BEV and 67.4% for PHEV owners, and it is a function of manufacturing year, manufacturing company, vehicle types, the nature of use, daily usage period, and battery capacity. The BEVs owners indicated a reduction of daily operating costs by more than 60% and an obvious reduction of maintenance costs and schedules. Higher education institutions in Jordan have started establishing technical diplomas and undergraduate programs related to EV sciences, their economy, and maintenance.

Despite many issues addressed in this study about the challenges and barriers to EV development in Jordan, most predicted failures and barriers are common and general and not specific to the Jordanian market only; such problems are sponsored by research and development centers of manufacturing companies, and they resolve them during new editions of their EVs. These common problems are, for example, rapid battery degradation, low battery capacities, battery heating management, charging difficulties, and low performance in extreme hot and cold climates.

The most brightening cause of the rapid spreading and development of EVs in Jordan is the constant government support that appeared in different forms, including tax exemptions, charging facilities at large stations and roads, and other incentives. The second reason is the overprice of imported fossil fuel in the country, which makes the transmission to EVs faster and economically more feasible.

After-sale services lack experienced and skilled maintenance technicians. Therefore, this study recommends opening technical institutes to graduate technicians proficient in dealing with the EVs problems and able to sustainably communicate with new technologies in this context. Also, the Jordanian government should speed up the process of establishing more fast charging points in all areas and main roads of Jordan. It is expected that the mature Jordanian experience with EVs could enable them to lead major transformations to EVs in the MENA region.

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