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Review Article

Battery selection criteria for electric vehicles: techno-economic analysis

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ABSTRACT

In this study, different battery types to be used in the conversion of a small and light (600-1000 kg) internal combustion engine vehicle into an electric vehicle were analyzed. The study was conducted to ensure that this vehicle is suitable for urban use and has a range of approximately 100 km. Each battery technology capacity is evaluated to be approximately 15 kWh. While performing the techno-economic analysis of different battery types, it was taken into account that they provide the necessary energy for about 10 years. Seven different battery technologies (lead-acid, gel, Ni-Cd, Li-Ion, LiFePo4, LiPo, Ni-MH) were used for comparison. In the analysis; price assessment in US Dollars ($), 10-year investment cost, weight and volume values, weight and volume values required to produce 1 kWh of energy were presented in tables. In addition to these, a review of battery life was made. Finally, the advantages and disadvantages of battery technologies compared to each other are given. As a result of the study, it was seen that the cheapest technology for a 10-year lifespan was lead-acid technology. It has been determined that lead-acid technology is 30% cheaper than the second cheapest gel technology and 82% cheaper than the most expensive technology, LiPo technology. In the study, it was revealed that the lightest technology was LiPo. It has been determined that this technology is 85% lighter than gel technology. Besides this information, data on cycle life, self-discharge, advantages and disadvantages are presented in tabular form.

Keywords: Battery Selection, Electric Vehicle, Techno-Economic Analysis.

1. Introduction

The first electric vehicle (EA) model was developed by Professor Stratingh in the Netherlands in 1835 [1-2]. Then, in 1838, Robert Davidson was able to reach a speed of 6.4 km/h and produced the electric locomotive [3]. Lead-acid batteries were developed after 1859 and electric started to be used in vehicles [1].

The use of electric vehicles has increased in recent years. Therefore, the importance of electric vehicles has increased. Besides, the use of fossil fuel vehicles is decreasing and electric vehicles are in demand. In the face of this demand, every study on electric vehicles is important.

Storage units that provide chemical storage of energy and convert chemical energy into electrical energy are called batteries. The battery groups formed by the batteries are defined as the "battery group" [4].

In this study, an evaluation was made on the energy storage system required for the conversion of an internal combustion vehicle to an electric vehicle. The purpose of this evaluation is to provide information about the criteria for the selection of the battery system to be used in the electric vehicle. Within the scope of the criteria, price analysis, weight analysis, volume analysis, battery life and advantages and disadvantages were discussed comparatively.

2. Literature Review

Adedeji (2022) made an artificial neural network to calculate and simulate battery electric vehicle parameters with datasets from electric car manufacturers [5]. Bhosale et al. (2023), made a comparative life cycle analysis (LCA) of different batteries for automobile-mobile applications under the Indian electricity mix scenario. The analysis evaluates the emissions of lead-acid and Li-Ion battery technologies in different effect categories and proposes a better battery technology [6].

Xia and Li (2022), evaluated the environmental performance of vehicles, the environmental impacts of the life cycle of electric vehicles and compared them with the effects of internal combustion engine vehicles. In short, optimizing the power structure, upgrading battery technology, and improving recycling efficiency is of great importance for the widespread introduction of electric vehicles, closed-loop battery production, and sustainable development of resources, the environment, and the economy [7].

By Şenyürek et al. (2022), battery technologies used in electric vehicles and the causes of fires encountered in these technologies and fire response methods were examined. Through the results obtained from here, the possibilities of application in electric and semi-electric (hybrid) vehicles were evaluated [8].

Liu et al., (2022) investigated the development trends of battery chemistry technologies, technologies related to batteries, and technologies that replace batteries. Evaluations were made about pre-lithium battery technologies, lithium-based technologies, and battery technologies beyond lithium [9]

Zhao et al. (2022), reviewed both conventional electric vehicle (EV) batteries (lead-acid, nickel-based, lithium-ion batteries, etc.) and cutting-edge battery technologies (e.g. all-solid-state, silicon-based, lithium-sulfur, metal-air batteries, etc.), major component materials, operating characteristics, theoretical models, manufacturing processes, and end-of-life management [10].

Alyar (2022), analyzed the structure of electric cars. By examining the battery types used, detailed information was given and the fire risks in electric cars were evaluated [11].

Aggarwal and Chawla (2020), presented the process of converting a vehicle that uses gasoline as fuel (624 cc gasoline engine) to an electric vehicle suitable for the Indian automotive industry. They aimed to minimize the conversion and operating costs of the vehicle [12].

Özcan et al. (2021), explained the important concepts of batteries and the superior and weak aspects of the batteries used in the past and newly developed [13].

Liu (2021), compared battery electric vehicles with internal combustion engine vehicles based on the total cost of ownership. It is stated that the higher initial cost of electric vehicles can be recovered in as little as 5 years [14].

Saleh (2021), investigated the environmental effects of battery production used to reduce carbon dioxide emissions for harmful systems by comparing the general characteristics of different battery systems (Lithium-Ion batteries and Nickel Metal Hydride batteries) [15].

Gerssen and Faaij (2012), examined the expectations of current and new battery technologies for battery electric vehicles. Five selected battery technologies are evaluated in terms of battery performance and cost in the short, medium, and long term [16].

Çetin et al., modeled a Li-İon battery for electric vehicles in MATLAB/Simulink environment [17].

The production of vehicles that have a longer range and can be charged in a shorter time is increasing. Therefore, studies on energy storage and charging systems are among the main topics. Automobile manufacturers need to choose the right battery chemistry for the vehicles [18]. In parallel with the technological developments in recent years, electrochemical storage stands out among the storage techniques due to its better controllability and portability. Efe and Güngör (2022), examined battery types, working principles, advantages and disadvantages comparatively from the past to the present [19].

Therefore, it is important to consider the battery group, which is the main component of energy storage and charging systems, in terms of vehicle range, weight, price, safety, volume and other variables, and select it according to the needs. Otherwise, the resources will be used incorrectly, the cost will increase by purchasing more than the required storage system, or a vehicle that is likely to be idle will be obtained by establishing a system that does not meet the need.

Today, more and more users prefer electric vehicles, as battery prices fall and new battery technology enables automakers to produce cheaper models with longer ranges [20]. In today's electric vehicle technologies, four types of battery chemistry are prime candidates for automotive applications. These species are; lead-acid, gel, Ni-MH and lithium-based batteries. Due to their low cost, lead-acid batteries are widely preferred by manufacturers for systems such as starting/lighting/ignition [18].

In this study, lead-acid, gel, Ni-Cd, Li-Ion, LiFePo4, LiPo and Ni-MH batteries will be discussed.

3. Material Selection Method

In this study, an evaluation will be made on a vehicle produced in 1992 with the Alto model under the brand name Suzuki (Figure 1.). Techno-economic analysis of different battery types will be made that will provide the necessary energy for approximately 10 years to convert this vehicle into an electric vehicle suitable for urban use and with a range of 100 km. The mentioned vehicle is 610 kg in curb weight; it uses gasoline as its fuel type, and its engine has a displacement of 796 cc and a power of 40 HP (approximately 32 kW) [21]. It also has a maximum torque of 59 Nm. However, the vehicle can reach a maximum speed of 130 km per hour. In this direction, it is thought that the vehicle will travel up to 80 km/h and be used for passenger transportation. For the electric motor power to be used, 50% performance loss is envisaged in terms of speed and maximum torque to be achieved. Therefore, a 16 kW drive system will be sufficient for the movement of the vehicle. In a study, a drive system with a power of 2x8 kW and a nominal voltage of 96 V was found to be sufficient for the conversion of an internal combustion car weighing 1182 kg into an electric car [22]. To provide the 96 V nominal voltage value of the motor, the number of each battery group will be determined according to whether they are in parallel or series.

7 different battery technologies (lead-acid, gel, Ni-Cd, Li-Ion, $LiFePO_4$, LiPo, Ni-MH) will be evaluated as materials for comparison. In analysis; mass power density (kWh/kg), volumetric power density (kWh/liter), battery initial investment cost ($), 10-year battery life cost ($), cost for 1 kWh ($/kWh), weight (kg) and volume (liter) values will be examined and presented in tabular form. In addition to these, battery features, advantages, and disadvantages will be specified.

Weight and volume values are; will be calculated in line with the dimensions received from the manufacturer or vendor of the said battery technology.

Battery life will be presented in tabular form in line with the values to be obtained from scientific data. The advantages and disadvantages of the batteries compared to each other will be compiled and presented within the scope of the battery technologies discussed in line with the previous studies.

Figure 1. Suzuki Alto (1992), [23]

3.1. Price analysis

Since the initial investment cost is important for the storage system, which is an indispensable component for electric vehicles, the price of the battery pack to be purchased should be investigated. In this calculation, considering the conditions such as inflation, market activity, production, and political stability, it would be more accurate to calculate and compare the US

Dollar ($), which is a more stable and global currency than the Turkish Lira.

It is not possible to know how many storage units are needed to provide a range of 100 km in the city. The reason for this is that the characteristics of the vehicle to be used, road, driver performance, weather, traffic conditions and other variables have an effect. However, when a general average is taken in the light of the factory data of vehicles of different brands given in Table 1, calculations can be made on the fact that approximately 7 km can be traveled with 1 kWh of energy. Based on this, an energy storage unit with a capacity of approximately 14 kWh will meet the need for a range of 100 km.

The prices on the websites where electronic shopping can be made in Turkey are taken and Table 2 is created. Based on the assumption that the vehicle will be used at full capacity daily, it is thought that there will be 365 charge-discharge times a year. When the calculation is made by dividing the cycle life (charge-discharge) number of each battery technology by 365, the approximate lifetime of the batteries is found in years. Based on the approximate lifetime, the 10-year lifetime cost of the battery was made calculated. Considering the lead acid battery as an example; the cycle life appears to be 1000. That is 1000/365 ≅ 3, and the annual operating cost is the initial investment cost divided by the approximate lifetime. So 690($)/3(year) = 230($/year). When this value is multiplied by 10, the value of the 10-year lifetime cost in US dollars is reached.

As can be seen from Table 2, when a price comparison is made for approximately the same range, for a 10-year investment in the long run, the lead-acid battery technology, which is seen as the cheapest, is 30% cheaper than the gel battery technology, which is the cheapest technology after it, and the most expensive it can be seen that it is 80% cheaper than the LiPo technology. When Figure 2 is examined, it is seen that LiPo technology is more costly than other technologies in terms of both initial investment cost and 10-year lifetime cost. Since the Ni-MH battery technology has a 10-year lifespan, it is natural that both costs are equal. This can be considered an ideal alternative for situations where battery replacement is difficult and costly. Lead-acid seems to be the cheapest technology in terms of initial investment cost and 10-year lifetime cost, and preferably gel batteries can also be evaluated.

Table 1. Battery capacity and range for vehicles of various brands and models [24]

Brand	Model	Battery Capacity (kWh)	Range (km)	km/kWh	Battery Type
Renault	Zoe	44.1	300	6.80	Li-İon
Audi	e-Tron	95	320	3.37	Li-İon
Porsche	Taycan	93.4	400	4.28	Li-İon
Tesla	Model S	75	417	5.56	Li-İon
Tesla	Model X	72.5	420	5.79	Li-İon
Tesla	Model 3	75	500	6.67	Li-İon
Peugeot	208 EV	46	340	7.39	Li-İon
BMW	i3	42.2	460	10.9	Li-İon
Opel	Corsa EV	46	330	7.17	Li-İon
Mini	Cooper SE	28.9	232	8.03	Li-İon
BMW	X3	74	420	5.68	Li-İon
Puegeot	2008 EV	46	310	6.74	Li-İon
Jaguar	I-Pace	90	470	5.22	Li-İon
Mercedes	EQC	78	403	5.17	Li-İon
Hyundai	Kona EV	67.1	305	4.55	Li-İon
Kia	Niro EV	67.1	450	6.71	Li-İon
Seat	e-Mii EV	36.8	260	7.07	Li-İon
Skoda	Citigo EV	36.8	270	7.34	Li-İon
VW	E-Up	32.3	290	8.98	Li-İon
Kia	Solu Ev	30	391	13.03	LiPo
Opel	Ampera -e	58	450	7.76	Li-İon
Saic MG	ZS EV	44.5	263	5.91	Li-İon
Citroen	C-Zero	15	130	8.67	Li-İon
Nissan	Leaf	40	370	9.25	Li-İon
	Average	55.6	354	7.00	

Table 2. Comparison of batteries in terms of price.

Battery Type	Brand	Voltage (V)	Capacity (Ah)	Energy (Wh)	Requirement (Piece)	Total Energy (kWh)	Range (km)	Unit Price (TL)	Unit Price ($)	Initial Investment Cost ($)	1 kWh Cost ($/kWh)	Cycle Life (Charge-Discharge)	Approximate Life (Years)	10-Year Lifetime Cost ($)	Source of Price
Lead-Acid	President	12.0	72.0	864.0	16	13.8	96.8	1095.0	58.9	943	68.2	1000	3	3143	[25]
Jel	Yiğit	12.0	90.0	1080.0	16	17.3	121.0	3695.0	198.9	3182	184.1	2500	7	4546	[26]
Ni-Cd	TNL	1.2	2.4	2.9	4800	13.8	96.8	29.9	1.6	7724	55.9	2000	6	12874	[27]
Li-İon	Orion	3.7	3.2	11.8	1300	15.4	107.7	102.4	5.5	7165	465.5	2000	6	11942	[28]
$LiFePO_4$	Ctechi	12.0	18.0	216.0	64	13.8	96.8	1929.0	103.8	6645	480.7	2000	6	11074	[29]
LiPo	Power Xtra	3.7	5.0	18.5	728	13.5	94.3	272.0	14.6	10657	791.3	2000	6	17762	[30]
Ni-MH	TNL	1.2	2.7	3.2	4400	14.3	99.8	57.0	3.1	13498	946.9	3000	10	13498	[31]

Table 3. Weight Comparison of Battery Technologies for Approximately 15 kWh (± %10) Capacity

Battery Type	Total Piece	Total Energy (kWh)	Weight (kg/piece)	Total Weight (kg)	Energy Density (Wh/kg)	Source of Price
Lead-Acid	16	13.8	18.5	296	46.7	[32]
Gel	16	17.3	25.5	408	42.4	[33]
Ni-Cd	4800	13.8	0.048	230.4	60.0	[27]
Li-Ion	1300	15.4	0.065	84.5	182.2	[28]
LiFePo4	64	13.8	2.3	147.2	93.9	[29]
LiPo	728	13.7	0.0836	60.9	224.3	[35]
Ni-Mh	4400	14.3	0.0305	134.2	106.2	[31]

Table 4. Volume Comparison of Battery Technologies for Approximately 15 kWh (± %10) Capacity

Battery Type	Total Piece	Total Energy (kWh)	Width (cm)	Length (cm)	Height (cm)	Volume (liter/piece)	Total Volume (liter)	Volumetric Energy Density (Wh/liter)	Source of Price
Lead-Acid	16	13.8	27.8	17.5	19.0	9.240	147.9	93.4	[32]
Gel	16	17.3	26.0	21.6	16.7	9.378	150.0	115.1	[33]
Ni-Cd	4800	13.8	4.3	2.3	2.3	0.023	109.1	126.6	[27]
Li-İon	1300	15.4	6.5	1.8	1.8	0.021	27.4	562.2	[28]
LiFePo4	64	13.8	18.1	7.8	17.1	2.414	154.5	89.4	[29]
LiPo	728	13.7	15.0	7.0	0.4	0.044	32.1	425.2	[35]
Ni-Mh	4400	14.3	1.4	5.0	1.0	0.007	30.8	462.8	[31]

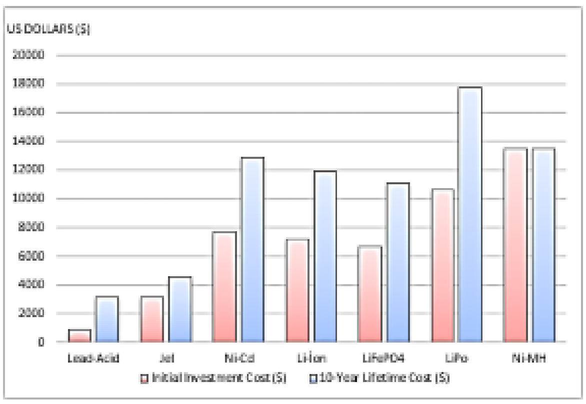

Figure 2. Comparison of initial investment costs and 10-year lifetime cost of different battery types for approximately 15 kWh (±%10) energy capacity

3.2. Battery weight and volume analysis

One of the most important for electric vehicles is the model. It is obvious that the range that the total storage vehicle can travel will decrease. The most effective and efficient use of the vehicle in terms of the load is used. Therefore, less energy consumption than a significant part of the weakness needs to be examined.

Data on each battery technology was obtained from nationally traded websites and table 3. was created. When Table 3 is examined, it is seen that there is an order of gel, lead-acid, Ni-Cd, LiFePO4, Ni-MH, Li-Ion and LiPo from the heaviest to the lightest. It is seen that LiPo battery technology, which is the lightest technology, is 86% lighter than gel technology, which is the heaviest technology.

Likewise, an important criterion in terms of energy storage in an electric vehicle is the volume of the battery pack. Considering that the vehicle design will be shaped according to the area to be occupied by the battery group, it is seen that the group with less volume will be advantageous. It is seen that the line that takes up the least space in terms of volume is LiFePO4, gel, lead-acid, Ni-Cd, LiPo, Ni-MH, and Li-Ion. In addition, the least footprint Li-Ion technology appears to take up 82% less space than the most compact LiFePO4 technology. These two tables, while evaluating the LiPo battery technology with both scale and taste, come to the fore and the preference wants to be appreciated.

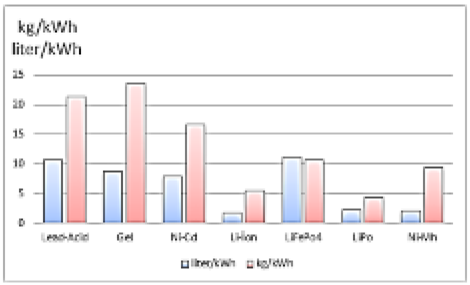

Figure 3. The comparison of the battery weight and volume for 1 kWh of energy

In Figure 3, the required weight and volume amount to obtain 1 kWh are given graphically. As can be seen from the graph, Ni-MH and Li-Ion technologies give much more weight to the volume they cover. Again, as can be seen from the graph, lead-acid and gel technologies are not preferable in terms of both criteria.

3.3. Battery Life

To eliminate range problems in electric vehicles, the need for batteries has increased, however, long-lasting use of batteries has become inevitable due to the limited raw materials required in production and the high costs [35]. Due to the deep discharge cycle, the life of the battery decreases and this reduces the performance [1]

With the long life of the batteries, the costs are reduced. One of the most important criteria for battery life is the self-discharge rate. The self-discharge rate is a measure of how long the battery loses its energy due to unwanted chemical reactions in the battery when it is not in use, and it changes according to the battery chemistry and temperature [36]. It is called a “cycle” when the battery is discharged to a certain depth of discharge and then fully charged [37] The cycle life of the battery is a parameter that determines its useful life, that is, its economic life. The main thing in determining the life of the battery is not the duration but the number of fill-discharge [38]

If some batteries are charged repeatedly after being partially discharged, they will gradually lose their usable capacity due to a decrease in operating voltage. This is called the memory effect in batteries [39]

In this context, the battery cycle life, self-discharge rate and memory effect given in Table 6. should be analyzed well [40].

As can be seen from Table 5., Ni-MH batteries have the longest cycle life, and if a vehicle with a range of 100 km is charged-discharged every day, they can have a lifespan of approximately 9-10 years. When we look at lead-acid batteries, which are also the cheapest battery technology, it can be seen that they can have a lifespan of about 3 years under the same conditions. Considering only the financial situation, it is considered that lead-acid batteries will be more advantageous despite their short life span.

3.4. Advantages and disadvantages of the battery technologies

In addition to the points mentioned above, some situations that should be considered in battery selection are given in table 5.

Table 5. The Comparison of Battery Properties for Approximately 15 kWh (± %10) Capacity

Battery Type	Energy(Wh)	Total Energy (kWh)	Total Piece	Cycle Life (Charge-Discharge)	Self-Discharge Loss (For a Month)	Memory Effect
Lead-Acid	864.0	13.8	16	1.000	%5	No
Gel	960.0	15.4	16	2.500	%2	No
Ni-Cd	28.8	13.8	480	2.000	%10	Yes
Li-İon	30.0	14.4	480	2.000	%5	No
$LiFePo_4$	240.0	13.4	56	2.000	%5	No
LiPo	18.5	13.7	738	2.000	%5	No

Ni-MH	3.2	14.3	4400	3.000	%20	Rare

Table 6. Advantages and disadvantages of battery technologies [41-43]

Battery Type	Advantages	Disadvantages
Lead-Acid	Relative cheapness Nearly 50 years of technology The breadth of the production volume	Weight Possibility of maintenance Low energy and power density Containing lead
Gel	Efficiency at low and high temperature Maintenance free Environmentally friendly Resistance to vibration, liquid contact, abrasion and impact	Weight Overcharge and short-circuit susceptibility Charge at a low voltage value
Ni-Cd	Long lasting Recyclable To be able to discharge completely without being damaged	Environmental pollution when not properly disposed of Expensive in use for vehicles
Li-İon	High energy density Good performance at high temperature Recyclable Low memory effect High-specific power High-specific energy Long lasting	High cost Length of charging time The risk of fire and explosion
$LiFePo_4$	Since it is produced with the development of Li-Ion technology, it shows similar properties. Easy to shape Light	Short-lived High cost
Ni-MH	Harmless to the environment Recyclable Safe working under high voltage Long cycle life Wide operating temperature range	Decrease in usable power due to memory effect Decreased cycle life in case of discharge with high current

As can be seen in Table 6, the selection of batteries is presented comparatively in terms of criteria such as operating temperature range, production flexibility of the material, possible effects on the environment and human health, battery recyclability and battery life.

4. Conclusion and Discussion

In this study, a techno-economic analysis of different battery types that will provide the necessary energy for approximately 10 years to transform a vehicle produced in 1992 with the Alto model under the Suzuki brand into an electric vehicle with a range of approximately 100 km, suitable for urban use, was carried out. Seven battery technologies were evaluated in the analysis. In the evaluation, initial cost, 10-year cost, weight, volume, mass power density (kWh/kg), volumetric power density (kWh/liter), and weight and volume criteria to be used for 15 kWh of energy are presented in tables. The study was also presented to evaluate the advantages and disadvantages of battery technologies.

As a result of the study, it was seen that for a 10-year investment, the cheapest lead-acid battery technology was 30% cheaper than the next cheapest technology, gel battery technology, and 82% cheaper than the most expensive technology, LiPo technology.

It is seen that LiPo battery technology, which is the lightest in terms of weight, is 85% lighter than gel technology, which is the heaviest technology.

Although Li-Ion technology has come to the fore in the use of electric vehicles in recent centuries, it is not right to ignore other technologies completely. While LiPo and Li-Ion output are required in projects where the weight parameter is prominent, Li-Ion will be the right choice if the storage area is small for storage. If an environmentally friendly and maintenance-free technology is desired for parts where weight and volume parameters are not important, gel technology can be preferred. In addition to these situations, if the vehicle usage distribution is wide, Ni-MH can be preferred due to its wide temperature range and safe operation under high voltage.

Regarding the vehicle whose conversion is considered; it should be taken into account that the range is limited to 100 km, the weight of the vehicle is relatively low, the vehicle is only used for passenger transportation, and the budget is limited. For this reason, it was decided that the battery technology, which will provide the energy required for the conversion of the Suzuki brand Alto model into an electric vehicle with a range of approximately 100 km, can be lead-acid due to its cheapness.

CRediT authorship contribution statement

Ahmet Samancı: Problem definition, Conceptualization, Methodology, Writing - review & editing.

Alaattin Yücenurşen: Investigation, Methodology, Writing - original draft, Writing - review & editing.

Declaration of conflicting interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

5. References

1. Ünlü, N., Karahan, Ş., Tür, O., Uçarol, H., Özsu, E., Yazar, A., Turhan, L., Akgün, F., Tırıs, M. “Elektrikli Araçlar,” TÜBİTAK Marmara Araştırma Merkezi Enerji Sistemleri ve Çevre Araştırma Enstitüsü, Gebze, Turkey, 2003.

2. Sayın, A.A., Yüksel, İ. “Elektrikli Renault Fluence aracı, lityum- iyon bataryasının modellenmesi ve batarya yönetimi,” Mühendis ve Makine, 52, (616), 75-82, 2011.

3. Chan, C.C. “The rise & fall of electric vehicles in 1828–1930: lessons learned,” Proceedings of the IEEE, 101 (1), 206 – 212, 2013.

4. Can Güven, E., Gedik K., “Environmental Management of End-of-life Electric Vehicle Batteries” Iğdır Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 9 (2), 726-737, 2019.

5. Adedeji, B. P., “A Novel Method for Estimating Parameters of Battery Electric Vehicles,” Intelligent Systems with Applications 15, 1-31, 2022.

6. Bhosale, A. P., Bodke, K., Babhulkar, A., Amale, S., Mastud, S. A., & Chavan, A. B., “Materials Today: Proceedings Comparative environmental assessment of different battery technologies used for electric vehicles,” Materials Today: Proceedings, 2023.

7. Xia, X., & Li, P., “A review of the life cycle assessment of electric vehicles: Considering the influence of batteries,” Science of the Total Environment, 814, 152870, 2022.

8. Şenyürek, Ü., Soyhan, H. S., & Çelik, D. D. C., “Battery Caused Fires in Electric Vehicles,” Uluslararası Yakıtlar Yanma ve Yangın Dergisi, 10, (1), 21–27, 2022.

9. Liu W., Placke T, Chau K.T. “Overview of batteries and battery management for electric vehicles,” Energy Reports, 8, 4058-4084, 2022.

10. Zhao, G., Wang, X., & Negnevitsky, M., “Connecting battery technologies for electric vehicles from battery materials to management,” IScience, 25, (2), 103744, 2022.

11. Alyar H., “Elektrikli Otomobillerin Yapısı ve Yangın Riskleri,” Mühendislikte Yakıtlar, Yangın ve Yanma Dergisi, 10(1), 1-8, 2022.

12. Aggarwal, A., & Chawla, V. K., “A sustainable process for conversion of petrol engine vehicle to battery electric vehicle: A case study,” Materials Today: Proceedings, 38, 432–437, 2020.

13. Özcan, Ö. F., Karadağ, T., Altuğ, M., & Özgüven, Ö. F., “Elektrikli Araçlarda Kullanılan Pil Kimyasallarının Özellikleri ve Üstün Yönlerinin Kıyaslanması Üzerine Bir Derleme Çalışması,” Journal of Science, 8, (2), 276–298, 2021.

14. Z. Liu et al., Comparing total cost of ownership of battery electric vehicles and internal combustion engine vehicles, Energy Policy, 158, 112564, 2021.

15. Saleh, S. A. G., “An Investigation on the Comparison of the Performance of Lithium- Ion Batteries and Nickel Metal Hydride,” Master. Thesis, Karabük University, 2021

16. Gerssen-Gondelach, S. J., & Faaij, A. P.

C., "Performance of batteries for electric vehicles on short and longer-term", Journal of Power Sources, 212, 111–129, 2012.
17. Çetin, S. M., Karakaya, B., & Gençoğlu, M.T., "Elektrikli Araçlar İçin Lityum İyon Bataryaların Modellenmesi," Fırat Üniversitesi Müh. Bil. Dergisi, 33, (2), 755–763, 2021.
18. Ekici, Y.E. and Tan N., "Farklı Batarya Tiplerinin Şarj ve Deşarj Karakteristiklerinin Hibrit Araç Modeli Üzerinde İncelenmesi," International Conferance on Innovatiive Engineering Applications, Cumhuriyet University, Sivas, Turkey, 2017
19. Efe, Ş., & Güngör, Z. A., "Geçmişten Günümüze Batarya Teknolojisi. European Journal of Science and Technology, 32, 947–955, 2022.
20.https://www.tehad.org/2021/04/27/elektrikli-otomobil-ve-calisma-prensibi/,10/10/2022
21.http://www.arabalar.com.tr/suzuki/alto/1992/0-8-gl ,10/10/2022
22. E. Akbıyık and A. Gören, "Şehir İçi Bir Aracın Kullanım Profilinin Saptanarak Elektrikli Taşıta Dönüştürülmesinde Üç Faz AA Motoru ve FDA Motoru Tercihleri ile Farklı Batarya Paketi Seçimlerinin Karşılaştırılması," Kastamonu Univ. J. Eng. Sci. 4(1), 11– 24, 2018.
23.https://commons.wikimedia.org/wiki/Category:Suzuki_Alto_(3rd_generation)#/media/File: Suzuki_Alto_1992.jpg , 06/10/2022
24.https://www.ucay.com.tr/blog/elektrikli-arac-sarj-istasyon-batarya-gucleri/,06/10/2022
25.https://www.trendyol.com/president/12v-72ah-600cca-aku-2020-petlas-uretimi-p-46241235?boutiqueId=61&merchantId=205089&utm_source=aff_t&utm_medium=cpc&utm_campaign=cimri_urun_listeleme&adjust_tracker=1xed9e_u72in2&adjust_campaign=cimri_urun_listeleme , 07/10/2022
26.https://urun.n11.com/aku/12v-90ah-80-ah-ebatinda-amper-jel-yigit-aku-P467915164?gclsrc=aw.ds&gclid=EAIaIQobChMIwYKs4P7N-gIVzdnVCh0CsgAeEAQYASABEgKZ1vD_BwE, 07/10/2022
27.https://www.trendyol.com/tnl/2400mah-sc-nicd-sarjli-supurge- matkap-pili-p-59191066, 07/10/2022
28. https://www.hepsiburada.com/orion-18650-3-7v-3200-mah-bms-devreli-sarjli-pil-pm-HBC00000ZAU01, 12/10/2022
29. https://www.n11.com/urun/12-v-18ah-lityum-demir-fosfat-aku-lifepo4-ctechi-4064444?magaza=solarmagazam&gclsrc=aw.ds&gclid=EAIaIQobChMIw5rK4oDOgIVz7LVCh13hA2JEAQYASABEgJjzPD_ Bw E , 07/10/2022
30. https://www.direnc.net/37v-5000- mah-li-polymer-pil , 07/10/2022.
31.https://www.infostar.com.tr/tnl-2700mah-12v-puntali-aa-basliksiz-nimh-sarj-edilebilir-pil, 07/10/2022.
32.https://urun.n11.com/aku/president-72-ah-amper-aku-2-yil-petlas-garantisi-2021-uret-P418696028,12/10/2022.
33.https://www.yigitaku.com/wp-content/uploads/2019/11/YD-12-80-AH_AGM-brosur.pdf , 07.10.2022
34. https://www.robotistan.com/37v-5000ma h- lipo-pil-devreli, 12/10/2022
35. F. Şahin and E. Kılınç, "Elektrikli Araç Batarya Aktif Dengeleme Sistemleri için Çift Yönlü Flyback Dönüştürücü Tasarımı," Politek. Derg., 0900, 2021.
36. B. Aydın, "Yakıt Pilli Elektrikli Araçların Tahriki İçin Farklı Tipte Batarya Gruplarının Belirlenmesi," PhD Thesis, Yıldız Technical University, 2010.
37. Ö. F. Özcan, T. Karadağ, M. Altuğ, and Ö.F. Özgüven, "Elektrikli Araçlarda Kullanılan Pil Kimyasallarının Özellikleri ve Üstün Yönlerinin Kıyaslanması Üzerine Bir Derleme Çalışması," J. Sci. 8, (2), 276-298, 2021.
38. K. Ogura and M. L. Kolhe, "Battery Technologies for Electric Vehicles," Electric Vehicles: Prospects and Challenges 139- 167, 2017.
39. T. Sasaki et al., "Memory Effect in a Lithium-Ion Battery," Nat. Mater. 12, (6); 569-575, 2013.
40. J. Ying, V. K. Ramachandaramurthy, K. Miao, and N. Mithulananthan, "A Review on The State-of-The-Art Technologies of Electric Vehicle, İts İmpacts and Prospects," Renew. Sustain. Energy Rev. 49, 365–385, 2015.
41. Y. Muratoğlu and A. Akkaya, "Elektrikli Araç Teknolojisi ve Pil Yönetim Sistemi-İnceleme," Elektr. Mühendisliği Derg. 458, 10-14, 2016.
42. A. Gelen and E. Tüfekçioğlu, "Lityum-Polimer Piller için Şarj ve Dengeleyici Devre Tasarımı," Erzincan Üniversitesi Fen Bilim. Enstitüsü Derg. 13, (2), 839-846, 2020.

43. F. Un-Noor, S. Padmanaban, L. Mihet-Popa, M. N. Mollah, and E. Hossain, "A Comprehensive Study of Key Electric Vehicle (EV) Components, Technologies, Challenges, Impacts, and Future Direction of Development," Energies, 10, 1-82, 2017.