# Comparative Analysis of Lead Acid and Lithium-ion Battery Used in Toto

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**Law & Management**

**Jadavpur University**

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## CERTIFICATE OF RECOMMENDATION

This is to certify that the thesis entitled "**Comparative Analysis of Lead Acid and Lithium-ion Battery Used in Toto**" is a bonafide work carried out by **Mr. Ankit Raj** under our supervision and guidance for partial fulfillment of the requirements for the Post Graduate Degree of Master of Technology in Energy Science and Technology, during the academic session 2021-2023.

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# CERTIFICATE OF APPROVAL

This foregoing thesis is hereby approved as a credible study of an engineering subject carried out and presented in a manner satisfactory to warranty its acceptance as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned does not endorse or approve any statement made or opinion expressed or conclusion drawn therein but approves the thesis only for the purpose for which it has been submitted**.**

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# DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

I hereby declare that this thesis contains a literature survey and original research work by the undersigned candidate, as part of his Master of Technology in Energy Science and Technology studies during the academic session 2021-2023.

All information in this document has been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that, as required by these rules and conduct, I have fully cited and referred all materials and results that are not original to this work.

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# NOMENCLATURE

| | |
|---|---|
| **Li** | Lithium |
| **CO2** | Carbon dioxide |
| **SO2** | Sulfur dioxide |
| **NO** | Nitric Oxide |
| **Km** | Kilometer |
| **KJ** | Kilo joule |
| **LFP** | Lithium iron phosphate |
| **VRLA** | Valve regulated Lead Acid |
| **PVGCS** | Photovoltaic grid connected system |
| **COE** | Cost of energy |
| **PV** | Photovoltaic |
| **ULABs** | Used lead acid battery |
| **AC** | Alternating Current |
| **DC** | Direct Current |
| **Rs** | Rupees |
| **LCOE** | Levelized Cost of Energy |
| **EV** | Electric vehicle |

# Table of Contents

# List of Figures

# List of Tables

# Chapter-1

# Introduction

## 1.1 Introduction

India has the second-largest road network in the world (kms) with a total length of 5.89 million kilometres. 90% of India's total passenger traffic commutes on the country's road network, which transports 64.5% of all commodities in the nation. Indian roads carry 85 per cent of the passengers and 70 per cent of the freight traffic of the country [36]. Indian roads are overcrowded with various types of vehicles such as cars, buses, trucks, and tractors along with bicycles, rickshaws and e-vehicles such as toto, electric cars and auto etc.

Toto are battery-operated vehicles used for short-distance transportation. They have gained significant popularity in many countries, particularly in densely populated urban areas, as an eco-friendly and cost-effective mode of transport. The background and significance of toto can be understood from various perspectives:

Environmental Impact: Toto are considered an environmentally friendly alternative to traditional fossil fuel-powered rickshaws or auto-rickshaws. They produce zero tailpipe emissions, thus reducing air pollution and improving urban air quality. By using electric power, toto contribute to the mitigation of greenhouse gas emissions and help combat climate change.

Sustainable Transport: Toto play a crucial role in promoting sustainable transport solutions. They offer a cleaner mode of transportation compared to conventional vehicles, as they rely on electricity, which can be generated from renewable energy sources.

Economic Opportunities: Toto have created employment opportunities, particularly for low-income individuals. Many people who were previously engaged in manual rickshaw pulling or other informal occupations can now become toto drivers or owners, earning a more stable income. The affordability of toto and the potential for micro-entrepreneurship have helped improve livelihoods and alleviate poverty in certain communities.

Last-Mile Connectivity: Toto are well-suited for short-distance commuting, especially in crowded urban areas or congested marketplaces [5]. They provide a convenient mode of transportation for the "last mile" connectivity, connecting commuters from transportation hubs, such as bus or train stations, to their final destinations. This enhances accessibility, reduces travel time, and improves overall urban transport efficiency.

Reduced Noise Pollution: Compared to traditional rickshaws or auto-rickshaws, totos operate quietly due to their electric motors. This helps in reducing noise pollution, making them suitable for residential areas, hospitals, educational institutions, and other noise-sensitive locations.

Government Policies and Incentives: Many governments around the world have recognized the potential of toto in achieving sustainable urban transportation goals. Delhi government and Indian government has implemented e-vehicle policy and provided incentives to promote the adoption of toto. These measures include financial subsidies, tax incentives, and regulatory frameworks that support the growth of toto fleets.

## 1.2 Role of batteries in Toto performance

Batteries play a crucial role in the performance of toto. As electric vehicles, Toto rely on batteries to store and supply electrical energy to power the vehicle's electric motor.Figure 1.1 shows toto with lead acid battery. Here are some key roles that batteries play in Toto performance:

- Power Source: Batteries serve as the primary power source for toto. They store electrical energy that is used to propel the vehicle forward. The capacity and performance of the battery directly impact the range and speed of the Toto. Higher-capacity batteries can store more energy, allowing for longer distances to be covered on a single charge.
- Energy Efficiency: The efficiency of the battery affects the overall energy consumption of the toto. Higher-efficiency batteries convert a larger portion of stored energy into useful electrical power, reducing energy losses and maximizing the range of the vehicle.
- Range and Endurance: The battery's capacity determines the range a toto can travel on a single charge. A larger capacity battery allows for longer journeys without the need for recharging. The range of an toto is a critical factor for its usability and

practicality as a mode of transportation, particularly for longer trips or in areas with limited charging infrastructure.

- Performance and Speed: The battery's power output capability influences the acceleration and top speed of a toto. Batteries with higher power output can deliver more electrical energy to the motor, resulting in better acceleration and higher speeds. The battery's ability to provide sustained power also affects the toto's performance on inclines or when carrying heavier loads.
- Charging and Recharging: The battery's charging characteristics and recharging time significantly impact the overall usability and productivity of toto. Batteries with fast charging capabilities enable quicker turnaround times, allowing Toto drivers to cover more trips in a day. Additionally, the battery's cycle life, or the number of charge-discharge cycles it can withstand before its performance degrades, affects its longevity and overall cost-effectiveness.
- Safety and Reliability: Batteries must meet stringent safety requirements to ensure the safe operation of toto. Battery management systems are employed to monitor and control the charging, discharging, and temperature of the battery to prevent overcharging, overheating, and other potential safety hazards. Reliable batteries with a low risk of malfunction or failure contribute to the overall safety and dependability of toto.

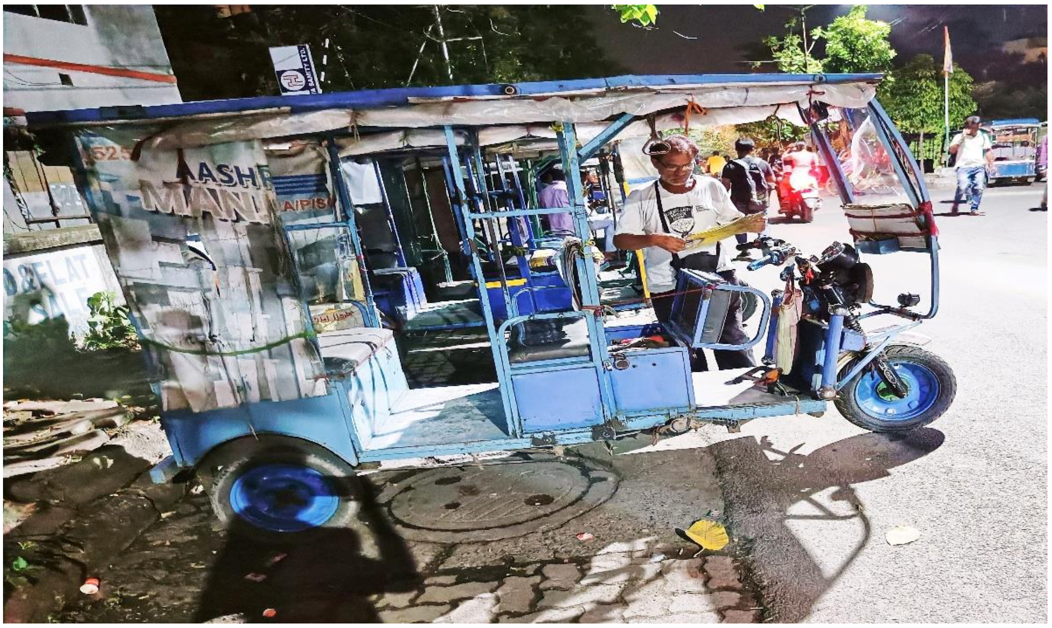

Figure 1.1 Image of a Lead acid battery toto

## 1.3 Objective

The objective of a comparative analysis between lead-acid and Lithium-ion batteries in toto is to evaluate and compare their performance, characteristics, and suitability for use in toto. The analysis aims to provide insights into the advantages and disadvantages of each battery technology, considering various factors such as energy efficiency, battery life, charging capabilities, cost-effectiveness, and environmental impact. The specific objectives of this analysis may include:

1. To compare the energy efficiency of lead-acid and Lithium-ion batteries by examining their ability to convert stored energy into useful electrical power. Evaluate the impact of energy efficiency on the overall range and performance of toto.
2. To assess the capacity and energy density of lead-acid and Lithium-ion batteries to determine the range an toto can cover on a single charge. Analyze the impact of battery capacity on the endurance and usability of the vehicle.
3. To evaluate the charging characteristics of lead-acid and Lithium-ion batteries, including charging time and compatibility with existing charging infrastructure. Assess the feasibility of fast charging and the availability of charging stations for each battery technology.
4. To compare the lifespan and cycle performance of lead-acid and Lithium-ion batteries. Assess the number of charge-discharge cycles each technology can withstand before its performance deteriorates and the need for battery replacements.
5. To analyze the initial cost, maintenance requirements, and overall cost of ownership associated with lead-acid and Lithium-ion batteries. Consider factors such as battery price, lifespan, energy efficiency, and charging infrastructure costs.
6. To evaluate the environmental impact of lead-acid and Lithium-ion batteries throughout their lifecycle, including raw material extraction, production, usage, and disposal. Assess factors such as carbon emissions, resource depletion, and recyclability.
7. To compare the safety aspects and maintenance requirements of lead-acid and Lithium-ion batteries. Consider factors such as safety risks, battery management

systems, maintenance procedures, and the need for specialized handling and disposal.

## 1.4 Statement of the Problem

The rapid growth in urbanization and the need for sustainable transportation options have led to the increased adoption of toto as an environmentally friendly alternative in urban areas. The battery technology employed in toto is a critical determinant of their overall performance, efficiency, and economic viability. This study aims at conducting a comparative analysis is to assess and compare the suitability and effectiveness of lead-acid and Lithium-ion batteries used in toto.

The study aims to investigate the following research questions:

Performance Analysis: What are the key performance characteristics of lead-acid and Lithium-ion batteries used in toto, including energy density, charge/discharge efficiency, cycle life, cost of the battery, charging cost, distance of trip and How do these characteristics impact the toto's range, speed, overall performance and profitability.

Environmental Impact: What are the environmental implications associated with the use of lead-acid and Lithium-ion batteries in toto? How do these battery types differ in terms of greenhouse gas emissions, energy consumption, and overall environmental sustainability throughout their life cycle?

Economic Implications: What are the economic considerations when choosing between lead-acid and Lithium-ion batteries for toto? How do the initial investment costs, operating expenses, and overall cost of ownership compare between the two battery types?

Safety and Regulatory Compliance: What are the safety aspects of using lead-acid and Lithium-ion batteries in toto? How do these battery technologies align with safety standards and regulatory requirements?

Figure 1.2 Toto carrying passengers

## 1.5 Conclusion

Toto have emerged as a sustainable and socially inclusive mode of transportation. They address the challenges of urban congestion, air pollution, and limited access to transportation in densely populated areas. The proliferation of toto represents a positive step toward creating cleaner, greener. Advancements in battery technology, such as the development of more efficient and high-capacity Lithium-ion batteries, have greatly improved the performance and viability of toto. As battery technology continues to evolve, totos are expected to become even more efficient, with longer ranges and shorter charging times, further enhancing their performance and widespread adoption. By conducting a comparative analysis of lead-acid and Lithium-ion batteries in toto, stakeholders can make informed decisions regarding the most suitable battery technology based on their specific requirements, considering factors such as performance, cost, environmental impact, and long-term sustainability.

# Chapter-2

# Literature Review

## 2.1 Review of the Earlier work

**Deepanjan Majumdar, Tushar Jash[1]** had done study on Merits and Challenges of E-Rickshaw as An Alternative form of Public Road Transport System: A Case Study in the State of West Bengal in India. The present work is based on a case study in West Bengal state where the travel pattern of these vehicles has been studied. The average specific energy consumption of the e-rickshaws has been found to be 53.76 kJ/passenger-km, which is the most efficient among other forms of motorized three-wheeled passenger vehicles. This study also delineates the challenges that stand in the way of proper implementation of these e-rickshaws in the public transport sector. The study revealed that the e-rickshaws are energy efficient than other forms of motorized public road transport vehicles in the state. Proper implementation of the e-rickshaws has the potential to address the issues of environmental pollution due to transportation as the specific CO2 emission for the e-rickshaws was found to be 19.129 gm/passenger-km. E-rickshaws have the potential to reduce the fuel oil consumption for passenger transportation which may lead to both economic and environmental benefits.

**B.V. Rajanna, Malligunta Kiran Kumar[2]**, had done Comparison study of lead-acid and Lithium-ion batteries for solar photovoltaic applications. The knowledge that they share are the viability and ability of battery energy storage systems based on battery usage in Solar Photovoltaic utility grid-connected systems. The power supply quality and reliability are improved by utilizing battery energy storage technologies in conjunction with solar photovoltaic systems. This paper presents a comparative analysis of Lead-Acid Storage battery and Lithium-ion battery banks connected to a utility grid. Here they have used two batteries Lead-Acid Storage Battery and Lithium-Ion Battery having a rating of 582.5 V at 100 % SOC and 100 Ah Capacity for analysis and performed simulations to understand the discharging and charging performance of the batteries. Throughout the discharging time as observed in our simulation study, Lithium-Ion battery has delivered the higher power to the utility grid. for cost comparision they have taken various parameters in to consideration to calculate overall cost ,such as, Battery Cost, Maintenance cost, Depth of Discharge, Cycle Life, Battery Life, and Battery Efficiency. Results show that Lithium-

Ion battery has better discharging voltage, discharging current than Lead-Acid Storage battery at various percentages of state of charge. It is also observed that while maintaining constant load voltage, Lithium-Ion battery delivers more power to utility grid. Lead-Acid battery consumes more power when charged to 100% state of charge. Lead-Acid Storage Battery is 2.79 times costlier than Lithium-Ion Battery. So, for a solar photovoltaic system with high power demand, a Lithium-Ion battery is more suitable both performance-wise and cost-wise.

**Hardik Keshan [3]** had done study on Comparison of Lead-Acid and Lithium Ion Batteries for Stationary Storage in Off-Grid Energy Systems**.** He compares the lead-acid and Lithium ion battery, for stationary energy storage. The various properties and characteristics are summarized specifically for the valve regulated lead-acid battery (VRLA) and Lithium iron phosphate (LFP) Lithium ion battery. He compared lead-acid and Li-ion batteries in four aspects: efficiency, life cycle, charging/discharging performance and cost analysis Batteries are a widely used and increasingly important component of stationary energy systems. Many different factors show advantages of Li-ion over lead-acid batteries for stationary storage applications. The comparative study reviews major factors that differentiate the two for better planning of energy storage installations. The comparison shows Li-ion to have higher efficiency and 5-10 times the life cycle of lead-acid. On charging and discharging, Li-ion outperforms lead-acid with wide margins. Cost analysis is less straightforward since lead-acid has a drastically lower upfront cost. The results and discussion here presented ultimately find that Li-ion batteries can even be preferable in terms of price when upfront cost is divided over the entire operational lifetime. For cost analysis Li-ion batteries are often dismissed for stationary storage projects with significant budget constraints because the lower price for lead-acid batteries translates to a lower cost per unit energy stored on a charge. Looking at energy stored throughout the expected lifetime, however, Li-ion batteries provide cheaper energy than lead-acid. In other words, by dividing the upfront cost over the energy stored times expected operational lifetime (number of charge discharge cycles), the price of energy is often several times cheaper for Li-ion than lead-acid batteries. Li-ion batteries have higher efficiency, longer lifetimes, faster charging capabilities, and lower incremental cost for energy supplied throughout their lifetime. Specifically for off-grid communities in tropical and semitropical developing countries, or any location where charging in freezing temperatures is not required, Li-ion batteries are a better long term investment than lead-acid.

**Abraham Alem Kebede , Thierry Coosemans , Maarten Messagie [4]** had done study on Techno-economic analysis of Lithium-ion and lead-acid batteries in stationary energy storage application. They studied a state-of-the-art simulation model and techno-economic analysis of Li-ion and lead-acid batteries integrated with Photovoltaic Grid-Connected System (PVGCS) were performed with consideration of real commercial load profiles and resource data. The Hybrid Optimization Model for Electric Renewables (HOMER) was used for the study of the techno-economic analysis. Besides, the performance of these batteries is greatly affected by the rate of charge and discharge cycling effects which gradually degrades the capacity of the battery. This effect was also investigated with MATLAB using a simplified equivalent circuit model by considering a typical stationary application datasheet. According to the result found, Li-ion batteries are techno-economically more viable than lead-acid batteries under the considered specifications and application profile. For both types of batteries with the same input parameters provided, the terminal voltage, SoC, current, and lifetime characteristics output of Li-ion batteries were found to be better than a lead-acid battery. Besides, it is found that the discharge characteristics response of Li-ion battery is better than lead-acid providing a longer lifetime for extraction of usable capacity. So, it can be taken as an indication for Li-ion batteries to be utilized in renewable generation based stationary application area with better energy capability. From studying about these batteries after experimentation, it can be concluded that, the PVGCS system with Li-ion batteries requires 40% lesser batteries as compared to lead-acid batteries and supporting in provision of reliable power supply with lower cost. Moreover, Li-ion batteries provided lower NPC and COE and the system that have a higher renewable fraction requires a higher number of batteries and vice-versa. In general, considering the typical application scenario under study, Li-ion batteries are found to be profitable in both technical and economic aspects.

**Ryutaka Yudhistira, Dilip Khatiwada , Fernando Sanchez[5]** had done study on A comparative life cycle assessment of Lithium-ion and lead-acid batteries for grid energy storage. Their study aims to evaluate the environmental impacts of Lithium-ion batteries and conventional lead-acid batteries for stationary grid storage applications using life cycle assessment. The nickel cobalt aluminum battery is the best performer for climate change and resource use (fossil fuels) among the analysed Lithium-ion batteries, with 45% less impact. The nickel cobalt manganese battery performs better for the acidification potential and particulate matter impact categories, with 67% and 50% better performance than lead-acid. The Lithium iron phosphate battery is the best performer at 94% less impact for the minerals and metals resource use category. The Lithium-ion batteries have fewer environmental impacts than lead-acid batteries for the observed environmental impact categories. However, this is not the case for the LFP(Lithium iron Phosphate) battery.

**Xi Tian, Yu Gong, Yufeng Wu[6]** had done study on Management of used lead acid battery in China: Secondary lead industry progress, policies and problems. They found out that the annual production of secondary lead from used lead acid batteries in China increased rapidly to 1.5 million tonnes in 2013, making china the world's largest secondary lead producer. Lots of illegal plants have been closed down, some advanced demonstration plants have been established, and some green hydrometallurgical processes have been developed by domestic institutes. However, the main existing problems are that, the proportion of secondary lead production is only 30% of the total lead production, the formal recycling network is chaotic and the overall level of industrial technology and equipment is outdated. Compared with developed countries, this paper predicts that secondary proportion will reach 44% in 2015 and 60% in 2028. Three typical American recycle models, including recycling led by battery manufacturers, secondary, and specialized recycling companies are suggested to be carried out in China. Finally more financial support and Best Available Technology Guide are suggested to be implemented by government to promote the advanced clean process to be applied nationwide.

**Rodolfo Dufo-López , Tomás Cortés-Arcos , Jesús Sergio Artal-Sevil [7]**had done study on Comparison of Lead-Acid and Li-Ion Batteries Lifetime Prediction Models in Stand-Alone Photovoltaic Systems**.** They studied models for estimating the lifetimes of lead-acid and Li-ion ($LiFePO_4$) batteries are analyzed and applied to a photovoltaic (PV)-battery standalone system. They compared the results obtained by each model in different locations with very different average temperatures at two different locations the Pyrenees mountains in Spain and Tindouf in Argelia. Classical battery aging models (equivalent full cycles model and rainflow cycle count model) are used by them and software tools are not adequate as they overestimate the battery life in all cases. For lead-acid batteries, an advanced weighted Ah-throughput model is necessary to correctly estimate its lifetime, obtaining a battery life of roughly 12 years for the Pyrenees and around 5 years for the case Tindouf. For Li-ion batteries, both the cycle and calendar aging are considered, obtaining more than 20 years of battery life estimation for the Pyrenees and 13 years for Tindouf. comparing a similar battery bank size in a PV-battery standalone system, the LiFePO4 battery life is expected to be around two times the lead-acid one. As the LiFePO4 battery cost at the end of 2020 can be around two times the Lead acid battery cost, this means that economically LiFePO4 batteries can be competitive with the Lead acid technology. Considering the expected reduction in Li-ion battery cost, we can expect that Li-ion batteries will be widely installed in PV-battery standalone systems in a few years.

**Md. Bashirul Islam, Md Khalekuzzaman, Sadib Bin Kabir and Md. Masud Rana[8]** had done Study on Recycling Used Lead-Acid Batteries (ULABs) in Bangladesh**.** They studied the recycling and management of used lead acid batteries (LABs) and a brief overview of manufacturing techniques, recycling processes, and regulatory controls of ULABs according to Bangladesh perspectives. As due to the increase in the application of LABs, the pollution caused by the LABs waste is also rising. In Bangladesh, the manufacturing and recycling of ULABs are practiced in both formal as well as informal sectors. Informal sectors use a coal-based open-pit smelting system to recover secondary lead without any pollution control equipment. Thus, the environment is polluted with harmful contaminants which ultimately causes health disorders. Lead-acid battery recycling would positively contribute to economic growth as well as mitigation of environmental pollution. The less contaminated environment would also assure the protection of the health of the workers and communities. Nevertheless, the old lead smelting techniques yield contaminated lead which causes major environmental pollutions. some companies in Bangladesh have already started to use recent eco-friendly technologies for obtaining pure lead from used lead acid batteries (ULABs).

**Elena M. Krieger, John Cannarella, Craig B. Arnold[9]** had done study on A comparison of lead-acid and Lithium-based battery behavior and capacity fade in off-grid renewable charging applications **.** they studied the effects of variable charging rates and incomplete charging in off-grid renewable energy applications are studied by comparing battery degradation rates and mechanisms in lead-acid, LCO (Lithium cobalt oxide), LCO-NMC (LCO-Lithium nickel manganese cobalt oxide composite), and LFP (Lithium iron phosphate) cells charged with wind-based charging protocols. Partial charging and pulse charging, common lead-acid stressors in off-grid applications, are found to have little if any effect on degradation in the Lithium-based cells when compared to constant current charging. These cells all last much longer than the lead-acid cells; the LFP batteries show the greatest longevity, with minimal capacity fade observed after over 1000 cycles. Excellent power performance and consistent voltage and power behavior during cycling suggest that LFP batteries are well suited to withstand the stresses associated with off-grid renewable energy storage and have the potential to reduce system lifetime costs. Deep discharge and incomplete charging, common off-grid stressors which accelerate aging in lead-acid cells, seem to have little impact on aging in these cells. As a result, battery systems for off-grid renewables could be sized much smaller for LFP cells. Capital costs are relatively high for LFP batteries compared to lead-acid cells, which can already account for a significant portion of the cost of standalone renewable energy systems. these studies suggest that LFP batteries may last many times longer than lead-acid cells in off-grid wind and solar applications and have significant potential to reduce energy storage costs over the lifetime of intermittent renewable energy systems.

**Suratsawadee Anuphappharadorn, Sukruedee Sukchai, Chatchai Sirisamphanwong[10]** had done study on Comparison the economic analysis of the battery between Lithium-ion and lead-acid in PV stand-alone application**.** They studied the economics analysis of 140 Wh photovoltaic (PV) stand-alone system by using a generic excel model using two different types of battery as Lithium-ion and lead-acid battery. they found out the cost of energy (COE), benefit cost ratio (BCR), and simple net present value( SNPV) of PV standalone system, which using Lithium-ion battery are 0.13, 34.93 baht/kWh and 145,927 baht, respectively. For the COE, BCR, and SNPV of PV stand-alone system, which using lead-acid battery are 0.19, 23.30 Baht/kWh and 89,143 Baht, respectively. The economic analysis of PV stand-alone using lead-acid battery are more suitable than PV stand-alone system using Lithium-ion battery, because an initial investment cost of the lead-acid battery is cheaper than Lithium-ion battery. However, Lithium-ion batteries have many advantages in comparison to lead-acid battery technology because they have high energy density, low maintenance, environment friendly and lifecycle is higher than lead-acid battery.

**Kalpna Varshney, Pradeep K. Varshney , Kajal Gautam , Monika Tanwar[11]** had done study on Current trends and future perspectives in the recycling of spent lead acid batteries in India. They studied that lead acid batteries are in ever increasing demand in various sectors and in return its scrap also increasing day by day. One of the best qualities of lead acid batteries is that these are almost completely recyclable and the lead metal can also be extracted out in largest percentage in recovery. Out of total lead usage 80% of lead is used in LABs. Maximum 100% lead can be recycled and recovered from the lead acid battery. New techniques like pyrometllurgy, hydrometallurgy and green technologies can be used for recycling in India apart from the traditional ones. In the Indian context there is a need for a mechanism to be evolved for the collection of spent batteries so that all the lead scrap can reach the genuine reprocessing units to recover lead in greater quantity and in an eco-friendly manner. Development of low cost and eco-friendly technology should be encouraged in order to sustain the recycling operation, which will not only meet the increasing demand for lead but also conserve the raw materials. Safe recycling of lead ensured by DRS (deposit refund system). Batteries management and handling rules (BMHR) are formulated and legally practiced in India.

**Aicha Degla ,Madjid Chikh , Achour Mahrane, Amar Hadj Arab[12]** had done study on Improved Lithium-ion battery model for photovoltaic applications based on comparative analysis and experimental tests **.** They studied that Lithium-ion (Li-ion) batteries have improved crucially and are widely regarded as a vital component in the expansion of renewable energy sources. Actually, they are still undergoing significant development, owing to their progressive spread from wearable electronics to more advanced fields such as electric vehicles and smart grids. Therefore, battery modeling facilitates forecasting, as well as efficient operation and precise energy predictions.

**Selamat Muslimin, Zainuddin Nawawi , Bhakti Yudho Suprapto , Tresna Dewi[13]** had done study on Comparison of Batteries Used in Electrical Vehicles **.**The electric vehicles (EVs) become very popular this day as an effect of the demand in order to reduce automobile emissions. One of current interest is to provide the equipment related to efficient electric power and to reduce air pollution, especially CO2 emissions. Batteries have been the main energy source for a long time to EVs. The efficiency of battery is about how much power the battery can charge and discharge concerning battery capacity. The battery management system (BMS) has a crucial role in ensuring about safety and performance of batteries. In general, there are two categories of batteries based on the ability of recharging, they are primary and secondary battery. The primary battery is type that can only be used once after being fully discharged. The secondary battery is type of battery that able to be recharged after discharging process. In EVs, it requires rechargeable battery with long cycle life, less of energy loss, high power density and sufficient safety level. Some types of batteries that used in EVs such as Lithium-ion (Li-ion), lead acid, nickel-cadmium (NiCd) and nickel-metal hydride (NiMH), etc. Li-ion battery becomes the most popular power supply implemented for Evs. Li-ion battery is significantly better than other types of battery, Lithium-ion battery has obvious advantages such as a long cycle life, high energy capacity and high efficiency also Li-ion battery is also composed of eco-friendly materials without toxic gassing problem and has high safety level.

**Ashleigh Townsend and Rupert Gouwshad[14]** done study on A Comparative Review of Lead-Acid, Lithium-Ion and Ultra-Capacitor Technologies and Their Degradation Mechanisms. They studied tha**t** As renewable energy sources, such as solar systems, are becoming more popular, the focus is moving into more effective utilization of these energy sources and harvesting more energy for intermittency reduction in this renewable source. This article aims to investigate what causes this degradation, what aggravates it and how the degradation affects the usage of the battery. This investigation will lead to the identification of a gap in which this degradation can be decreased, prolonging the usage and increasing the feasibility of the energy storage devices. Comparing the various degradation causes for the mentioned ESDs, a few commonalities can be obtained. Over-discharging, over-charging and increased internal resistance (IR) are the three most common causes amongst the ESDs, the first of which is more specific for BESS and not so much for UC. Increases in IR are generally due to all the other causes—electrolyte and active material ionic mobility, separator efficiency, concentration polarisation and temperatures as ESD degrades the internal resistance increases, reducing the ability of the ESDs to supply the specified capacity and thus reducing the overall capacity of the ESDs .

**Aimie Nazmin Azmi, Norhafiz Salim, Aziah Khamis[15]** had done study on Analysis of an energy storage sizing for grid-connected photovoltaic system. They studied that paper present on the analysis of an energy storage sizing for a small grid-connected PV system. This project is to study the proper sizing of energy storage (battery) in a grid-connected PV system for consumers whom purchase and sell electricity from and to the utility grid. The goal is to minimize the total cost of the operation for a consumer with a PV system with a battery storage system. The sizing of energy storage has been carried out by using two types of batteries which is Lead-acid battery and Lithium-ion battery. For both batteries, the same amount of PV output, similar load and same cost is used in the simulation. There is a major difference of the minimum cost between the lead-acid battery and Li-ion battery. By comparing two types of energy storage, the ideal capacity value for both type of battery can be determined when the operational cost goes to its minimum.

**Chao Peng , Fupeng Liua , Zulin Wang , Benjamin P. Wilson , Mari Lundström[16]** had done study on Selective extraction of Lithium (Li) and preparation of battery grade Lithium carbonate (Li2CO3) from spent Li-ion batteries in nitrate system. They studied a novel method that allows selective extraction of Lithium and production of battery grade Li2CO3 is introduced, which includes nitration, selective roasting, water leaching and Li2CO3 preparation. By this method, metallic components in Li-ion battery waste are firstly transformed into corresponding nitrates, and then decomposed into insoluble oxides during roasting except for Lithium nitrate, which is ready to be extracted by water leaching. The obtained Lithium-rich solution (34.1 g/L Lithium) is then subjected to a carbonation step at 95 °C for 30 min to form the desired $Li2CO_3$. The purity of $Li2CO_3$ produced is up to 99.95%, a level above the minimum standards required for battery grade $Li2CO_3$.

**Yue Yang, Wei Sun, Yongjie Bu, Chenyang Zhang, Shaole Song, and Yuehua Hu[17]** had done study on Recovering metal values from spent Lithium ion battery via a combination of reduction thermal treatment and facile acid leaching studied. Traditional acid leaching process for leaching metal values from spent Lithium-ion batteries (LIBs) is low efficiency and inevitably consumes large amounts of reductants. Here, a novel process, based on reduction thermal treatment and reductant-free acid leaching, for recycling valuable metals from spent LIBs has been developed . Finally, almost 100% Li and Co were easily leached from reaction product under the conditions of 2.25 M $H2SO_4$, 80 oC, 30 min and Co and Li in leaching liquor were further separated with 35% PC88 at the ratio of aqueous to organic (A:O) equaling 0.5, 25 oC and pH=5.5. In this study, a more effective process with the combination of reduction thermal treatment and facile acid leaching has been developed for recycling valuable metals from spent LIBs. The thermodynamics calculation and practical thermal treatment experiments indicate that LiCoO2 can be reduced to CoO and $Li2CO_3$ by graphite at 600 oC. The optimum conditions for reduction of LiCoO2 is 600 oC, 120 min and molar ratio of $LiCoO_2$ to graphite=2:1.

**Enas A. Othman, Aloijsius G.J. van der Ham, Henk Miedema, Sascha R.A. Kersten[18]** had done study on Recovery of metals from spent Lithium-ion batteries using ionic liquid. They studied A separation method to selectively recover valuable metals (Co, Ni, Mn and Li) from synthetic spent Lithium-ion battery cathodes leachate using a fatty-acid-based ionic liquid, tetraoctylphosphonium oleate is demonstrated. The investigated parameters for this selective separation and recovery process include extraction pH, contact time and composition of the regeneration solution. The benefit of using this ionic liquid is that > 99 % of Co and > 99 % of the Mn can be separated from the Ni and the Li by a two-stage extraction process. A subsequent single regeneration process separates the Co from the Mn. In a single-stage extraction at 8 M HCl (pH =-0.9), more than 99 % of the Co and 89% of the Mn can be extracted. The subsequent separation of Mn from Co can be achieved by a regeneration process using a composite solution containing ammonia, ammonium carbonate and ammonium sulphate and in which Co remains in the raffinate and Mn precipitates as $MnCO_3$.

**Cry S. Makola , Peet F. Le Roux and Jaco A. Jordaan[19]** had done study on Comparative Analysis of Lithium-Ion and Lead–Acid as Electrical Energy Storage Systems in a Grid-Tied Microgrid Application **.**They observed that Microgrids (MGs) are a valuable substitute for traditional generators. They can supply inexhaustible, sustainable, constant, and efficient energy with minimized losses and curtail network congestion. This work investigated the technical survey of Li-ion and Lead acid batteries and their ability to withstand variable DC load demands in the MG. The operation of both electrochemical energy storage technologies was investigated in the proposed MG system using a variable DC load profile.

**Sam Booth , Dan Olis and James Elsworth[20]** had done study on Comparative study of techno- economics of Lithium-ion and lead acid batteries in micro- grids in sub-saharan Africa . This report takes a close look at the cost of batteries in microgrids to evaluate whether Lithium-ion (Li-ion) or lead-acid batteries are optimal to minimize costs, and it assesses which operational practices for batteries lead to the lowest life-cycle cost (LCC). Batteries often make up 20%–30% of capital costs during the life of a micro-grid system, so managing these costs and better understanding what drives them are important elements of sustainable business models for developers and funders who are considering investing in this sector. This study points to a great deal of additional research to be done on battery degradation in micro-grids, in particular taking existing models and calibrating them to the ever-growing amount of real-world data coming from micro-grid systems to improve the accuracy of performance forecasting and economic analysis.

**Mehdi Hamid Vishkasougheh, Bahadir Tunaboylu[21]** had done study on Characterization of a Li-ion battery based stand-alone photovoltaic system. They reviewed that the number of photovoltaic (PV) system installations is increasing rapidly. This document presents a recommended design for a battery based stand-alone photovoltaic system (BSPV). BSPV system has the ability to be applied in different areas, including warning signals, lighting, refrigeration, communication, residential water pumping, remote sensing, and cathodic protection. The presented calculation method gives a proper idea for a system sizing technique. Based on application load, different scenarios are possible for designing a BSPV system. In this study, a battery based stand-alone system was designed. The electricity generation portion was a three a-Si panel system connected in parallel and for storage a LFP battery was used. The high power LFP battery packs are 40 cells each 8S5P (configured 8 series 5 parallel). Each individual pack weighed 0.5 kg and is 25.6V.

Istanbul, Ankara and Adana were chosen in order to evaluate the effect of temperature and solar irradiation on the a-Si panel efficiency. Temperature and solar irradiation were gathered from reliable sources and by using translation equations, current and voltage output of panels were calculated.

**Meher Kumar[22]** had done study on Comparision on study of Lithium ion & lead acid charging and discharging characteristics. A Lithium-ion or Li-ion battery is a type of rechargeable battery which uses the reversible reduction of Lithium ions to store energy Lithium batteries, as opposed to alkaline, are capable of giving off a strong energy surge after a long period of low discharge. This makes them ideal for fire alarms. Alkaline batteries provide good, long term power, but they lose strength over time. On the other side , the Lead acid battery are inexpensive compared to newer technologies, lead–acid batteries are widely used even when surge current is not important and other designs could provide higher energy densities. The depth of discharge and battery capacity is strongly affected by the discharge rate of the battery. The battery capacity degrades due to sulfation and shedding of extra material. Lead acid Battery takes 425 seconds to full charge while Lithium Ion Battery takes 100 seconds to full charge. So charging of Lithium Ion battery is fastest. With initial state set to full charge, it was found that Lead Acid Battery discharge to 13.64% in 500 hours while Lithium Ion Battery in the same period discharge to 2.757% with load resistance set at 72 ohms in both cases. Lithium ion battery has many advantages over lead acid battery.

**Andre Tati Zau ,Mpho Lencwe , Sp Daniel Chowdhury and Thomas Olwalhad[23]** done study on A Battery Management Strategy in a Lead-Acid and Lithium-Ion Hybrid Battery Energy Storage System for Conventional Transport Vehicles**.** Conventional vehicles, having internal combustion engines, use lead-acid batteries (LABs) for starting, lighting, and ignition purposes. However, because of new additional features (i.e., enhanced electronics and start/stop functionalities) in these vehicles, LABs undergo deep discharges due to frequent engine cranking, which in turn affect their lifespan. Therefore, this research study seeks to improve LABs' performance in terms of meeting the required vehicle cold cranking current (CCC) and long lifespan. The performance improvement is achieved by hybridizing a lead-acid with a Lithium-ion battery at a pack level using a fully active topology approach. This topology approach connects the individual energy storage systems to their bidirectional DC-DC converter for ease of control. The two bidirectional DC-DC buck-boost converters step up the batteries' voltage to 13 V during CCA mode. During charging mode, the bidirectional DC-DC buck-boost converter steps down the DC bus voltage from 14.5 V to the charging reference voltage of 13.1 V for LAB and 14.2 V for LIB. The FLC is used to divide the required CCA between the batteries. The proposed hybrid Lead-acid and Lithium-ion energy storage system with BMS is designed, developed, and simulated using MATLAB software.

**Saket Tirpude, Ankit Bharadwaj , Rama Sundaram , Sidhartha Mane, Rajesh M Holmukhe[24]** had done study on An investigation into awareness and usage of lead acid batteries in E-rickshaws. The purpose of this study is to identify the reasons which contributed to the premature failure of the e-rickshaw battery that puts the e-rickshaw operator (ERO) in financial stress. This study investigates the technical concepts which are absent in the e-rickshaw technology like modern fast charging techniques such as Constant Current-Constant Voltage (CC-CV), Pulse Current, Superimposed Pulse Frequency, Intermittent- Current Charing, and Interrupted Charge-Control Techniques (ICCT) and the Hybrid Energy Systems. The most important criteria for the ERO is the affordability of the charger, because at last it is the ERO who has to purchase the charger. The pulse-based, ICT and the ICCT-based chargers employ heavy power electronics and complex designs which adds up to the cost. Thus, seeing the cost benefit, CC-CV based fast charger is more suited for the e-rickshaw technology. The CC-CV technique will also reduce the unit consumption at the charging stations, reducing the electricity tariffs. A fast charging algorithm added to these chargers will further increase the life cycles of the battery thus benefitting the EROs by enabling them to earn an extended margin of time pacifying their financial burden. Hybrid energy system consisting of the 48V lead-acid battery connected in parallel with ultra capacitor bank could be an additional technical step that can be taken to ameliorate the range anxiety of the ERO. Hybrid energy systems are known for sufficing both the need for power density as well as energy density which would make e-rickshaw technology much efficient.

**Navaneeth , Jithin , Anitha , Swathi , Advaith Uday [25]** had done study on An Overview of Batteries used for Electric Two-Wheelers in Indian Drive Cycle .The field of mobility is undergoing a deviation from conventional Internal Combustion Engine vehicles to Electric Vehicles .This paper provides an overview of various types of batteries used in Electric Vehicles and showcases the advantages that the Solid-State Batteries provides over the other chemistries of batteries, specifically Lithium-Ion Batteries which have liquid electrolyte. In this paper a conventional ICE bike was retrofitted to an E-Bike and the best battery in drive cycles in India was found. Various parameters like energy density, power density, safety, cost, cycle life, etc. were compared and showcased why Lithium based SSBs are promising for use in EV applications.

**Haonan Qin[26]** had done study on The Impact of Nanotechnology on Lithium-Ion Battery Used in Electric Vehicles**.** In recent years, the electric vehicles have developed rapidly. As a result, the components of the electric vehicles were logically achieved great success, particularly the rechargeable Lithium-ion battery. Fortunately, the nanotechnology, at the same time, made a great deal of huge achievements and appeared in numerous fields. Nanotechnology obviously plays a critical role in the field of Lithium-ion battery and nearly all elements of Lithium-ion battery are changed to varying degrees. This review firstly introduced some advanced research of anode nanomaterials for Lithium-ion battery, which is mainly about how to solve the volume expansion problem. A silicon nanomaterial with a graphitic carbon has been discussed. As for the cathode materials, the Lithium cobalt oxide, $LiFePO_4$, Lithium manganese oxide and nickel-rich cathode are discussed. Initially, the advantages and disadvantages of Lithium cobalt oxide cathode is discussed and the nanomaterials of Lithium cobalt oxide are reviewed. Secondly, the advantages and improvement method of $LiFePO_4$ are discussed. After that, the limitations of Lithium manganese oxide are listed. Finally, in the case of Lithium manganese oxide cathode, nanocoating is made to improve the performance.

**Praphun Pikultong, Sahataya Thongsan , Somchai Jiajitsawat[27]** had done study on The Study of Usable Capacity Efficiency and Lifespan of Hybrid Energy Storage (Lead-Acid with Lithium-ion Battery) Under Office Building Load Pattern. They have stated that One of the greatest practices in energy management is the Energy Storage System . ESS can be used for renewable energy control as well as peak shaving in the build-up of a Smart

Grid. The cost of a Lithium ion battery is more than 200 percent greater than that of a lead-acid battery, which is a significant barrier to project start-up. This paper focuses on the use of a hybrid energy storage system that includes a Lithium-ion battery and a lead-acid battery. Usable capacity efficiency was the most influential key factor as it related to the ratio of each type of battery reflecting the start-up cost of the project.

**Subash Gautam , Saddam Husain Dhobi[28]** had done study on Study and Analysis of lead Acid and Li-Ion Battery for Transport, Safa Tempo in Kathmandu Valley. The objective of this work is to compare the income generation and discharging nature of Lithium ion batteries and lead acid batteries which is powered safa tempo by Lithium ion battery of set Sinopoly $LiFePO_4$, 76.8 voltage, 300Ah and Trojan T125, lead acid batteries of a set of 72V, 240Ah for a loop of 9 km loop in Kathmandu Valley. The discharging nature of lead acid with loops is decreases continuously while for Lithium ion is constant for some initial loops and decrease constantly with loops while the nature of state of charge is same with loops. Also the price of lead acid batteries is 33% of Lithium ion batteries. After taking the data and analysis it is found that the income generated by Lithium ion battery is greater than that of lead acid battery is about 50% on a single charge and the energy consume by safa tempo powered by lead acid battery is greater than safa tempo powered by Lithium ion battery.

**Moti L. Mittal, Chhemendra Sharma and Richa Singh[29]** had done study on Estimates of emissions from coal fired thermal power plants in India. This paper presents emissions of carbon dioxide (CO2), sulfur dioxide ($SO_2$), and nitric oxide (NO) from thermal power plants in India for a period of nine years from 2001-02 to 2009-10. The emission estimates are based on a model in which the mass emission factors are theoretically calculated using the basic principles of combustion and operating conditions. Future emission scenarios for the period up to 2020-21 are generated based on the estimates of the nine years from 2001-02 to 2009-10. Power plants in India use different qualities of coal, different combustion technologies and operating conditions. The emissions per unit of electricity are estimated to be in the range of 0.91 to 0.95 kg/kWh for CO2, 6.94 to 7.20 g/kWh for SO2, and 4.22 to 4.38 g/kWh for NO. Emissions of greenhouse gases and other pollutants are increasing in India with the increasing demand for electricity.

# Chapter-3

# Methodology

## 3.1 Selection of vehicle and locations for survey

Toto has been selected as a vehicle for my research as it is greener and environment friendly in nature and it is a vehicle of current generation as it derives its power from the battery used in it. To conduct the comparative study related to the battery used in toto and its effect, 6 locations in different areas of kolkata were taken as data samples, with a total of 100 toto being sampled. A common questionnaire was used for all the areas to assess the socio-economic impact and the impact of the selection of battery either lead acid battery or Lithium ion battery on the performance of toto. The areas for the survey were chosen after considering the demographics, and the location within the state. To avoid a sampling selection bias, 6 areas with diverse characteristics were considered. The locations in Kolkata where the sampling was done : Mukundapur (location 1) , Barrackpore (Location 2), Dumdum (Location 3), New garia (Location 4), Newtown (Location 5), Dhulagarh (Location 6).

## 3.2 Data Collection methods:

Gather battery specifications and technical data for both lead-acid and Lithium-ion batteries used in toto. Conduct interviews with toto drivers and manufacturers to understand their experiences and preferences related to battery choices. Utilize surveys or questionnaires to collect data on performance metrics, such as range, charging time, and battery life, from toto owners or drivers. Obtain environmental impact data through Life Cycle Assessments for both types of batteries, considering the entire lifecycle from production to disposal. A survey was conducted based on the requirement at different locations in Kolkata. Every driver has been asked the questions regarding their vehicle ad their experiences with them. The questionnaire consists of the following questions:

1. Name of the owner of toto
2. Which battery is used in toto, Rated Voltage, Capacity (Ah) and cost of the battery.
3. Resale value of the battery
4. How long does each battery type typically last before needing replacement?
5. How long does it take to fully charge each battery type?
6. Which battery type has a faster charging time?

7. How far can the toto travel on a single charge with each battery type?
8. Have you observed any difference in the power output or performance of the E-Rickshaw when using Lead Acid vs. Lithium-ion batteries?
9. What kind of maintenance tasks are required for each battery type?
10. Have you experienced any instances of reduced performance or capacity degradation over time for either battery type?
11. How do you dispose of or recycle the batteries at the end of their life cycle?
12. How much do you earn from each half trip and distance of each half trip?
13. What is the electricity charges per month from charging the battery of toto?
14. What are your personal expenses per month?
15. Based on your experience, which battery type do you consider more suitable for toto, considering factors such as performance, maintenance, and environmental impact?

Conducting a comparative analysis of performance metrics, such as energy density, cycle life, energy cost per passenger per kilometer, total expenditure per passenger per kilometer, charging time and power density, between lead-acid and Lithium-ion batteries. Compare the environmental impacts of both battery types based on the data, including energy consumption, greenhouse gas emissions ($CO_2$, $SO_2$, NO). Perform cost analysis to assess the economic implications of using lead-acid and Lithium-ion batteries, considering initial investment, operating costs, and total cost of ownership.

## 3.3 Components of Toto

Electric Motor: BLDC type 650-1400W & 48V motor. It is controlled via an electronic controller. Advantages of brushless motors include long life span, little or no maintenance, and high efficiency.

Electronic Motor Controller: Electrical toto controller is one of the main component of the battery powered vehicle that governs its complete operation. The controller includes a manual or automatic switch turning the motor on/off, selecting forward or reverse motion, selecting and regulating speed.

Battery: Set of four 12V deep cycle lead acid/Li-ion batteries. These features, along with their low cost, make them attractive for use in motor vehicles to provide the high current required by starter motors.

Brakes: Drum brakes, actuated internally, expanding shoe type Steering: Handle bar type steering.

Front Suspension: Helical Spring with dampener with hydraulic telescopic shock absorbers. Rear Suspension, Leaf spring carriage spring with rear shocker. Differential: Chinese manufactured differential is used in toto which is connected to the electric motor and rear wheels.

Speedometer/Indicator: Speedometer generally used have analog dials. The one the left side indicates vehicle speed and one on the right side indicate battery charge level. It is connected to the controller unit.

Dc to Dc Converter: Practical electronic converters use switching techniques. Switched mode DC-to-DC converters convert one DC voltage level to another, which may be higher or lower, by storing the input energy temporarily and then releasing that energy to the output at a different voltage. It is designed to fulfill dc power requirement of e-rickshaw vehicle. It can be operated from 40v dc to 60v dc. Light weight, which allows to move from one place to another place. Input reverse connection protection.

Miscellaneous Spare parts: Centre locking, Alloy wheel, Rear light, Front glass, Front Indicator, Head light, Ignition switch, Charger, Converter, left-right switch, Type, Wirings, Throttle.

## 3.4 Working Principle of toto

Working of toto is based on DC motor, battery & suspension system different from conventional auto rickshaws. It uses a Brush Less DC motor ranging from 650-1400 Watts with a differential mechanism at rear wheels. The electrical system used in Indian cities is 48V. Some variants made in fiber are also in use due to their strength and durability, resulting in low maintenance. It consists of the controller unit. The battery used is mostly Lead acid/Li-ion battery. Toto have the same principle as EV's. The motors generally used here are DC motors. Mostly, toto are rear wheel driven. The drive train is seen below in

Figure 3.1. The power for the battery pack goes via an AC charger circuit with a rectifier to convert them into DC power. After charging the battery pack, the signals are sent to the electronic control unit (power converters & motor controllers). The purpose of these ECU's is to control speed according to the driver input (accelerator & brake). These pulses are then sent to the DC motor which transfer power to the wheels.

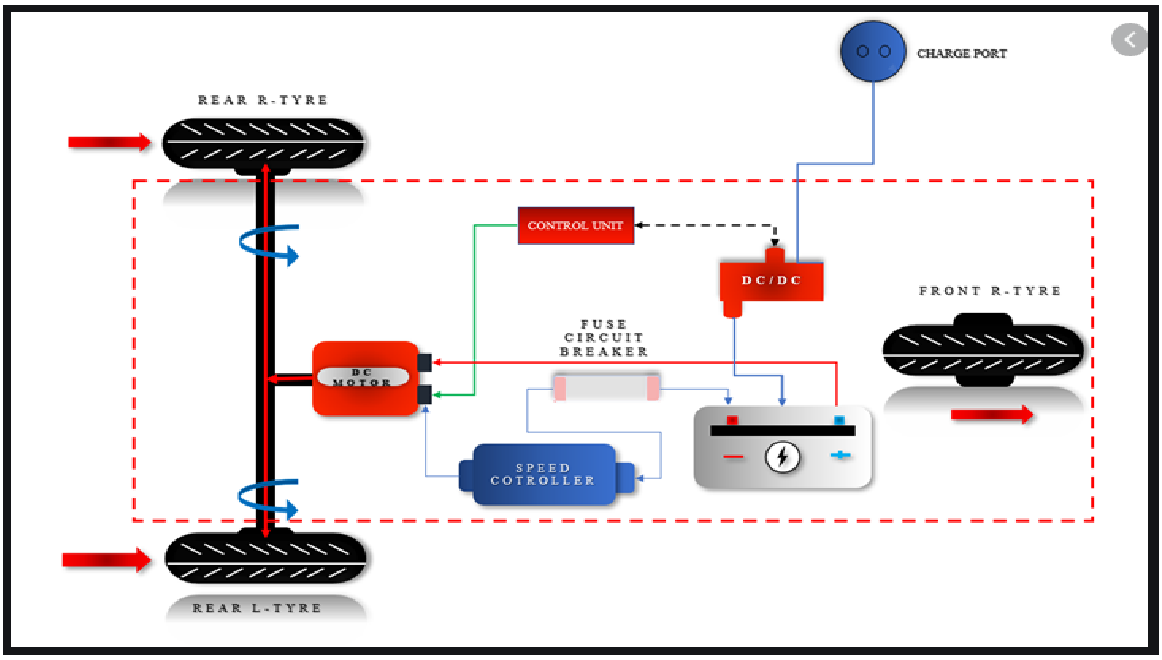


Figure 3.1 Transmission mechanism of toto

## 3.5 LEAD ACID BATTERY

Lead-acid batteries are a type of rechargeable battery widely used for various applications, including automotive starting, deep cycling, and backup power systems. They are known for their robustness, affordability, and ability to deliver high currents.

### 3.5.1 Construction:

In the lead acid battery construction, the plates and containers are the crucial components. The below section provides a detailed description of each component used in the construction. The lead acid battery diagram is shown below in figure 3.2

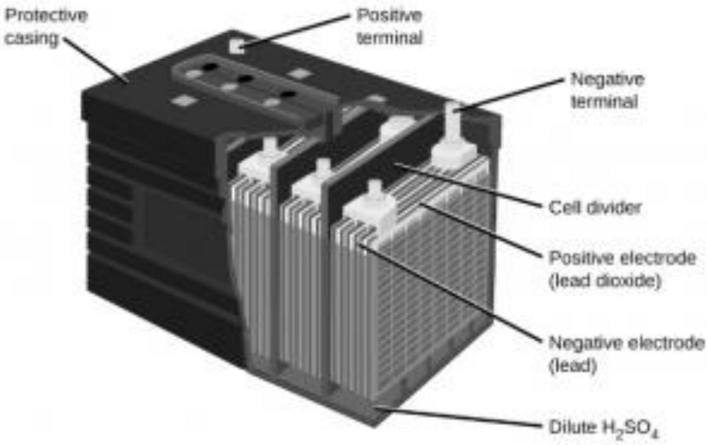


Figure 3.2 Inner construction of Lead acid battery

Container: This container part is constructed with ebonite, lead-coated wood, glass, hard rubber made of the bituminous element, ceramic materials, or forged plastic which are placed on the top to eliminate any kind of electrolyte discharge. Whereas in the container bottom section, there exist four ribs where two are placed on the positive plate and the others on the negative plate. The components that are utilized for the construction of the container should be free from sulfuric acid, they should not bend or permeable and do not hold any kinds of impurities which leads to electrolyte damage.

Plates: The plates in lead acid battery are constructed in a different way and all are made up of similar types of the grid which is constructed of active components and lead. Active Component are the component which actively involves in the chemical reaction processes that happen in the battery mainly at the time of charging and discharging is termed as an active component such as

Lead peroxide – It forms a positive active component.

Sponge lead – This material forms the negative active component

Diluted sulfuric acid – This is mainly utilized as an electrolyte

Separators: These are of thin sheets that are constructed of porous rubber, coated leadwood, and glass fiber. The separators are positioned in between the plates to provide active insulation. They have a grooved shape on one side and a smooth finish on other edges.

Battery Terminals: It has positive and negative edges having diameters of 17.5 mm and 16 mm [26].

The grid is crucial to establish conductivity of current and for spreading equal amounts of currents to the active components. If there is uneven distribution, then there will be loosening of the active component. The plates in this battery are of two kinds. Those are of plate/formed plates and Faure/pasted plates. The formed plates are mainly employed for static batteries and they have heavyweight and expensive too. But they have long durability and these are not easily prone to lose their active components even in continuous charging and discharging processes. These have minimal capacity to weight proportion. While the pasted process is mostly used for the construction of negative plates than that of positive plates. The negative active component is somewhat complicated and they experience a slight modification in charging and discharging processes.


Figure 3.3  Lead acid battery of different power rating

### 3.5.2 Working Principle of lead acid battery:

Lead-acid batteries operate based on an electrochemical reaction between lead and lead dioxide plates immersed in an electrolyte solution of sulfuric acid. Each battery cell consists of a positive electrode (lead dioxide), a negative electrode (lead), and a separator that prevents direct contact between the electrodes. During the charging process, electrical energy is applied to the battery, causing a chemical reaction that converts the lead dioxide into lead sulfate on the positive electrode and the lead into lead sulfate on the negative electrode. Simultaneously, sulfuric acid dissociates into hydrogen ions ($H^+$) and sulfate ions ($SO_4^{2-}$) in the electrolyte. During discharge, the stored chemical energy is converted back into electrical energy. The lead sulfate on the electrodes reacts with the sulfuric acid to form lead and lead dioxide, releasing sulfate ions and hydrogen ions into the electrolyte. The hydrogen ions combine with sulfate ions to form sulfuric acid, maintaining the concentration of the electrolyte. Figure 3.4 shows toto assembled with lead acid battery.

Characteristics of Lead-Acid Batteries:

- High Energy Density: Lead-acid batteries offer a relatively high energy density, enabling them to store a significant amount of electrical energy for their size and weight.
- Deep Discharge Capability: Lead-acid batteries can be discharged to a relatively low voltage without causing significant damage or capacity loss. This characteristic makes them suitable for applications requiring a sustained power supply over an extended period.
- Low Self-Discharge: Compared to some other battery chemistries, lead-acid batteries have a relatively low self-discharge rate. They can hold their charge for an extended period, making them suitable for applications where the battery may remain idle for some time.
- High Current Delivery: Lead-acid batteries are capable of delivering high currents, making them suitable for applications that require a sudden surge of power, such as starting an engine.
- Maintenance Requirements: Lead-acid batteries require periodic maintenance. This includes checking and topping up the electrolyte levels, ensuring proper charging, and occasionally equalizing the battery cells to prevent sulfation and maintain their performance.
- Environmental Considerations: Lead-acid batteries contain lead and sulfuric acid, which are hazardous materials. Improper disposal or mishandling can lead to environmental pollution. It is important to recycle lead-acid batteries appropriately to minimize their environmental impact.

Figure 3.4 Toto with assembled lead acid battery

### 3.5.3 Lead Acid Battery Chemical Reaction

The chemical reaction in the battery happens mainly during discharging and recharging methods and in the discharge process is shown in figure 3.5. When the battery is completely discharged, then the anode and cathodes are $PbO_2$ and Pb. When these are connected using resistance, the battery gets discharged and the electrons have the opposite path at the time of charging. The $H_2$ ions have a movement towards the anode and they become an atom. It comes in reach with $PbO_2$, thus forming $PbSO_4$ which is white in color as shown in equation 2. In the same way, the sulfate ion has a movement towards the cathode and after reaching, the ion is formed into SO4. It reacts with lead cathode thus forming lead sulfate as shown in equation 3.

$PbSO_4 + 2H = PbO + H_2O$ (1)

$PbO + H_2SO_4 = PbSO_4 + 2H_2O$ (2)

$PbO_2 + H_2SO_4 + 2H = PbSO_4 + 2H_2O$ (3)

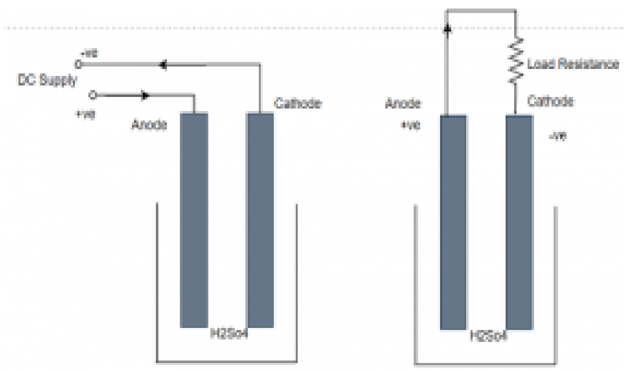


Figure 3.5 Current flow inside lead acid battery

During the recharging process, the cathode and anodes are in connection with the negative and positive edges of the DC supply. The positive $H_2$ ions move in the direction of the cathode and they gain two electrons and forms as H2 atom. It undergoes a chemical reaction with lead sulfate and forms lead and sulfuric acid as shown in equation 4.

$PbSO_4 + 2H_2O + 2H = PbSO_4 + 2\ H_2SO_4$ (4)

The combined equation for both the processes is represented in figure 3.6 below

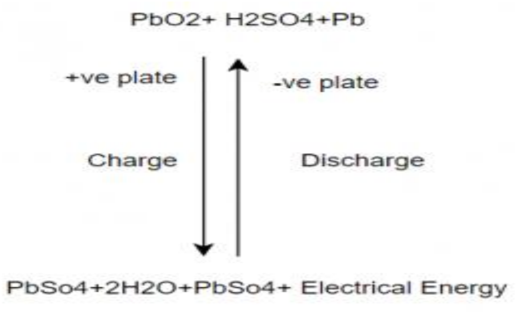


Figure 3.6 Reactions during charging and discharging

Here, the downward arrow indicates charge and an upward arrow indicates the discharge process.

## 3.6 Lithium-ion battery

Lithium-ion batteries are rechargeable energy storage devices widely used in portable electronics, electric vehicles, and renewable energy systems. They are known for their high energy density, long cycle life, and relatively low self-discharge. Lithium ion cylindrical cell has been shown in figure 3.7.

Figure 3.7: Lithium ion cylindrical cell

### 3.6.1 Working Principle:

Lithium-ion batteries consist of several key components:

1. Anode (Negative Electrode): The anode is typically made of graphite, which can intercalate Lithium ions. During charging, Lithium ions are extracted from the cathode and stored in the anode as Lithium intercalates.

2. Cathode (Positive Electrode): The cathode is usually made of a Lithium metal oxide, such as Lithium cobalt oxide ($LiCoO_2$), Lithium iron phosphate ($LiFePO_4$), or Lithium manganese oxide ($LiMn_2O_4$). When the battery discharges, Lithium ions move from the anode to the cathode through an electrolyte and intercalate into the cathode material.
3. Electrolyte: The electrolyte is a conductive solution or a solid polymer that allows the movement of Lithium ions between the anode and cathode during charge and discharge. It is typically composed of Lithium salts dissolved in an organic solvent
4. Separator: The separator is a porous membrane that physically separates the anode and cathode while allowing the passage of Lithium ions. It prevents direct contact between the electrodes, which could cause a short circuit.
5. During charging, Lithium ions move from the cathode through the electrolyte to the anode, where they are stored shown in figure 3.9. During discharge, the Lithium ions move back from the anode to the cathode shown in figure 3.8, creating an electric current that can be used to power devices.

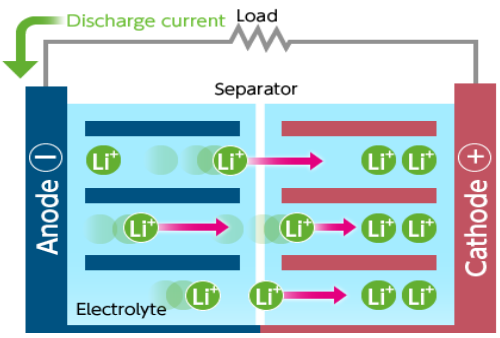


Figure 3.8: Li-ion flow during discharge

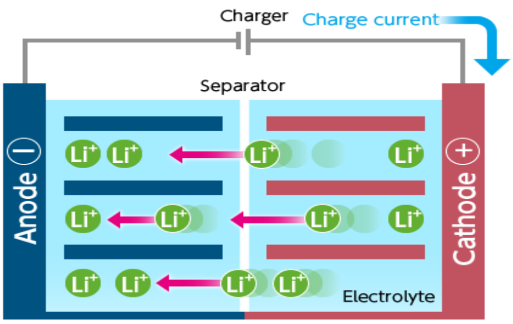


Figure 3.9: Li-ion flow during charge

### 3.6.2 Characteristics:

1. High Energy Density: Lithium-ion batteries used in toto as shown in Figure 3.10 offer a high energy density, meaning they can store a large amount of energy relative to their weight and volume. This makes them suitable for portable electronic devices where size and weight are crucial.
2. Rechargeable: Lithium-ion batteries are rechargeable, allowing them to be used multiple times. They can be charged and discharged hundreds or even thousands of times before their capacity significantly decreases.

3. Low Self-Discharge: Lithium-ion batteries have a low self-discharge rate compared to other rechargeable batteries. They can retain their charge for extended periods when not in use, which is beneficial for applications where long shelf life is important.
4. Memory Effect: Lithium-ion batteries do not suffer from the memory effect, a phenomenon that reduces the battery's capacity when it is not fully discharged before recharging. Users can recharge these batteries at any state of charge without impacting their overall capacity.
5. High Voltage: Lithium-ion batteries typically provide a higher voltage than other rechargeable batteries. The nominal voltage of a single Lithium-ion cell is around 3.7 volts, which allows for the efficient powering of many electronic devices.
6. Safety Considerations: While Lithium-ion batteries offer various advantages, they require careful handling due to safety considerations. Overcharging, overheating, physical damage, or manufacturing defects can lead to thermal runaway and, in rare cases, fire or explosion. Therefore, proper charging, use of protective circuits, and adherence to safety guidelines are essential.

Figure 3.10: Lithium ion battery used in toto

Figure 3.11: Lithium ion battery manufacturing plant

## 3.7 Cost analysis and economic feasibility

Lead-acid batteries are known for their relatively low cost compared to other battery technologies. However, the economic feasibility of using lead-acid and Lithium ion batteries depends on several factors, including the specific application, lifecycle costs, and alternative options.

Initial Cost: Lead-acid batteries have a lower upfront cost compared to many other battery technologies, such as Lithium-ion batteries. This cost advantage is primarily due to the mature manufacturing processes and widespread availability of lead-acid batteries. They are commonly used in automotive applications, where their affordability plays a significant role.

Operating and Maintenance Costs: While lead-acid batteries have a lower initial cost, it's important to consider the operating and maintenance costs over the battery's lifespan. Lithium ion has lower maintenance cost than lead acid. Some factors that contribute to the overall cost include:

- Cycle Life and Replacement: Lead-acid batteries have a limited cycle life and may need replacement more frequently than some other battery technologies. The need for replacement can add to the long-term costs.
- Maintenance: Lead-acid batteries require periodic maintenance, including checking and topping up electrolyte levels, equalizing charges, and ensuring proper charging. The cost of maintenance, including labor and materials, should be considered.
- Efficiency: Lead-acid batteries have lower charge and discharge efficiencies compared to some other battery chemistries. This means that more energy is required to charge them fully, resulting in higher electricity costs over time.
- Downtime and Backup Power: In applications where reliable and continuous power supply is crucial, lead-acid batteries may require additional backup units to compensate for potential downtime during maintenance or battery replacement. These backup units can contribute to the overall costs.

Lifecycle Costs: To assess the economic feasibility, it's important to consider the lifecycle costs of lead-acid batteries compared to alternative options. This includes evaluating the cost of battery replacements, maintenance, energy efficiency, and potential savings or benefits gained from using lead-acid batteries in specific applications.

Application-Specific Considerations: The economic feasibility of lead-acid batteries can vary depending on the specific application. For instance, lead-acid batteries are commonly used in automotive starting applications due to their affordability and ability to deliver high currents. In contrast, for long-duration, high-capacity energy storage applications, other battery chemistries like Lithium-ion or flow batteries may be more economically viable due to their higher energy density and longer cycle life.

## 3.8 Formula used for calculation

Energy density, Energy cost per passenger per km, Total expenditure per passenger per km, payback period of the battery and $CO_2$, $SO_2$, NO emission from powerplant which generates electricity for charging of the battery has been calculated using formula given in equation 1,2,3,5,7,8,9 respectively using the data collected from the survey.

$$\text{Energy density} = \frac{\text{Nominal battery voltage (V)} * \text{Rated battery capacity (Ah)}}{\text{Weight of Battery (Kg)}} \quad (1)$$

$$\text{Energy cost / passenger / km} = \frac{\text{Total charging cost in its lifetime}}{\text{(Number of passenger per half trip)} * \text{(Distance travelled in lifetime (km))}} \quad (2)$$

$$\text{Total Expenditure/ Passenger/ Km} = \frac{\text{Total expenditure}}{\text{(Number of passenger per half trip)} * \text{(Distance travelled in lifetime (km))}} \quad (3)$$

$$\text{Earning per month} = \text{Earning per half trip} * \text{Number of half trip per day} * 30 \quad (4)$$

$$\text{Payback period for battery} = \frac{\text{Total cost of batteries}}{\text{Net earning per day}} \quad (5)$$

$$\text{Payback period for toto} = \frac{\text{cost of toto}}{\text{Net earning per day}} \quad (6)$$

Whenever we generate electricity at the thermal power plant we tend to emit a lot of pollution. Major constituents of the pollution are $CO_2$ , $SO_2$ , NO etc. The amount of different pollutants emitted per KWh of electricity generation are [29]

$CO_2$ emitted per KWh of electricity generation = 0.91 Kg/KWh

$SO_2$ emitted per KWh of electricity generation = 6.94 g/KWh

NO emitted per KWh of electricity generation = 4.22 g/KWh

$CO_2$ emitted /Passenger/Km=

$$\frac{\text{Number of units of elctricity consumed} * 0.91}{(\text{Number of passenger per half trip}) * (\text{Distance travelled per month(km)})} \quad (7)$$

$SO_2$ emitted /Passenger/Km =

$$\frac{\text{Number of units of elctricity consumed} * 6.94}{(\text{Number of passenger per half trip}) * (\text{Distance travelled per month(km)})} \quad (8)$$

NO emitted /Passenger/Km =

$$\frac{\text{Number of units of elctricity consumed} * 4.22}{(\text{Number of passenger per half trip}) * (\text{Distance travelled per month(km)})} \quad (9)$$

One of the sample calculation has been shown below for lead acid battery used in toto at Mukundapur using the data collected from the toto driver at Mukundapur.

Charging cost /month = Rs. 1888.88

Total charging cost in its Lifetime = 1888.88*12*2.11 = Rs.47826.441

Cost of Distilled water / week = Rs. 130

Total cost of distilled water in its lifetime = 130*52*2.11 = Rs.14263.60

Number of Passenger /Half trip = 5

Number of half trip/Day = 17.88

Distance of each Half trip = 2.5Km

Life of Battery = 2.11 Years

Number of Km in Lifetime = 17.88*30*2.5*12*2.11 = 33954.12 Km

Energy cost / Passenger / Km = $\frac{47826.441}{5*33954.12}$ = Rs. 0.281 / Passenger / Km

Cost of New Battery = Rs. 8683.33

Total number of Battery = 4

Total cost of Battery = 4*8683.33 = Rs.34733.32

Resale value of Battery = Rs.2344.44

Total Expenditure = 47826.441 + 34733.32 + 14263.60 = Rs.96823.361

Total Expenditure / Passenger / Km = $\frac{96823.361}{5*33954.12}$ = Rs.0.570 / Passenger / Km

Earning / half Trip = Rs. 55.55

Earning / Month = 55.55*17.88*30=Rs.29797.02

Total Earning during Lifetime of battery = 17.88*55.55*30*12*2.11 = Rs.754460.54

Electricity cost / day = $\frac{1888.88}{30}$ = Rs. 62.962

Distilled water cost / day = $\frac{130}{7}$ =Rs.18.57

Earning /day = 17.88*55.55 =Rs.993.234

Expenditure / day = 62.962 + 18.57 = Rs.81.532

Net Earning / day = 993.234 – 81.532 = Rs.911.702

Average cost of toto = Rs.155000

Payback period for Battery = $\frac{34733.332}{911.702}$ = 38.097 days

Payback period for toto =$\frac{155000}{911.702}$ = 170.011 days = 5 months and 20.011 days

Total number of unit of electricity consumed = $\frac{1888.88}{7.31}$ = 258.39 unit of electricity

Number of km travelled / month = 17.88*30*2.5 = 1341 Km

$CO_2$ emitted / month = 258.39*0.91 = 235.1349 kg of $CO_2$ = 235134.9 g of CO2

$SO_2$ emitted / month = 258.39*6.94 = 1793.22 g of $SO_2$ =1.793 Kg of SO2

NO emitted / month = 258.39*4.22 = 1090.40 g of NO = 1.0904 Kg of NO

$CO_2$ emitted / Passenger / Km = $\frac{235134.9}{5*1341}$ = 35.06 g of $CO_2$ / Passenger / Km

$SO_2$ emitted / Passenger / Km = $\frac{1793.22}{5*1341}$ = 0.267 g of $SO_2$ / Passenger / Km

NO emitted / Passenger / Km = $\frac{1090.40}{5*1341}$ = 0.162 g of NO / Passenger / Km

Similarly I have calculated all the above parameters for both lead acid and Lithium ion battery used in toto at all the 6 locations in Kolkata from the data collected at the respective location from the toto drivers.

# Chapter-4

# Result and Discussion

Data obtained from the survey at different locations in Kolkata has been tabulated in the table given below:

TABLE 4.1: Data obtained for toto operating on lead acid battery in mukundapur

| Power rating(12V), Ah | Cost of new battery (per battery) (Rs) | Resale value (per battery) (Rs) | Life of Battery (years) | Distance travelled in full charge (Km) | Maximum speed (Km/hour) | Energy density (Wh/Kg) | Charging cost/month (Rs) | Number of half trip/day | Distance of each half trip (Km) | Earning /half trip(Rs) |
|---|---|---|---|---|---|---|---|---|---|---|
| 120 | 8000 | 2500 | 2.5 | 80 | 25 | 48 | 1300 | 20 | 2.5 | 50 |
| 130 | 9400 | 2500 | 2 | 90 | 27 | 50.32 | 1400 | 18 | 2.5 | 55 |
| 130 | 9400 | 2200 | 2.5 | 90 | 28 | 50.32 | 1500 | 15 | 2.5 | 50 |
| 100 | 7250 | 2000 | 1.5 | 70 | 20 | 42.85 | 2500 | 13 | 2.5 | 60 |
| 120 | 8000 | 2500 | 2.5 | 85 | 25 | 48 | 1500 | 20 | 2.5 | 55 |
| 140 | 10000 | 2500 | 2.5 | 110 | 25 | 52.50 | 1500 | 20 | 2.5 | 60 |
| 130 | 9400 | 2500 | 1.5 | 100 | 25 | 50.32 | 3000 | 15 | 2.5 | 60 |
| 130 | 9500 | 2400 | 2 | 100 | 25 | 50.32 | 1500 | 20 | 2.5 | 60 |
| 100 | 7200 | 2000 | 2 | 60 | 20 | 42.85 | 2800 | 20 | 2.5 | 50 |

TABLE 4.2: Data obtained for toto operating on lead acid battery in dumdum

| Power rating(12V), Ah | Cost of new battery (per battery) (Rs) | Resale value (per battery) (Rs) | Life of Battery (years) | Distance travelled in full charge (Km) | Maximum speed (Km/hour) | Energy density (Wh/Kg) | Charging cost/month (Rs) | Number of half trip/day | Distance of each half trip (Km) | Earning /half trip(Rs) |
|---|---|---|---|---|---|---|---|---|---|---|
| 100 | 7250 | 2000 | 2 | 65 | 20 | 42.85 | 2800 | 15 | 2.5 | 55 |
| 130 | 9400 | 2200 | 2.5 | 100 | 28 | 50.32 | 1500 | 15 | 3 | 60 |
| 100 | 7250 | 2000 | 1.5 | 75 | 22 | 42.85 | 1200 | 20 | 2 | 50 |
| 120 | 8500 | 2500 | 2.5 | 85 | 25 | 48 | 1300 | 18 | 3 | 60 |
| 130 | 9400 | 2200 | 2.5 | 100 | 28 | 50.32 | 1300 | 20 | 3 | 60 |
| 100 | 7500 | 2000 | 1.5 | 70 | 20 | 42.85 | 2800 | 14 | 3 | 65 |
| 120 | 8500 | 2500 | 2.5 | 85 | 25 | 48 | 1300 | 22 | 3 | 60 |
| 140 | 10000 | 2500 | 2.5 | 110 | 25 | 52.50 | 1500 | 20 | 2.5 | 60 |
| 130 | 9000 | 2500 | 2 | 100 | 30 | 50.32 | 1500 | 16 | 3 | 55 |
| 130 | 9500 | 2400 | 2 | 100 | 28 | 50.32 | 1800 | 15 | 3 | 60 |

TABLE 4.3: Data obtained for toto operating on lead acid battery in New garia

| Power rating(12V), Ah | Cost of new battery (per battery) (Rs) | Resale value (per battery) (Rs) | Life of Battery (years) | Distance travelled in full charge (Km) | Maximum speed (Km/hour) | Energy density (Wh/Kg) | Charging cost/month (Rs) | Number of half trip/day | Distance of each half trip (Km) | Earning /half trip(Rs) |
|---|---|---|---|---|---|---|---|---|---|---|
| 100 | 7250 | 2000 | 1.5 | 60 | 20 | 42.85 | 1500 | 15 | 3 | 55 |
| 140 | 10000 | 2500 | 2.5 | 110 | 25 | 52.50 | 3000 | 20 | 2.5 | 50 |
| 140 | 10000 | 2500 | 2.5 | 110 | 25 | 52.50 | 1500 | 20 | 2.5 | 60 |
| 130 | 9500 | 2500 | 2 | 100 | 20 | 50.32 | 1500 | 18 | 3 | 55 |
| 100 | 7500 | 2000 | 2 | 60 | 20 | 42.85 | 2800 | 20 | 3 | 60 |
| 140 | 10000 | 2500 | 2.5 | 110 | 25 | 52.50 | 1500 | 20 | 2.5 | 60 |
| 120 | 8500 | 2500 | 2.5 | 85 | 25 | 48 | 1300 | 15 | 3 | 65 |
| 100 | 7250 | 2000 | 1.5 | 70 | 20 | 42.85 | 1200 | 15 | 3 | 55 |

TABLE 4.4: Data obtained for toto operating on lead acid battery in Newtown

| Power rating(12V), Ah | Cost of new battery (per battery) (Rs) | Resale value (per battery) (Rs) | Life of Battery (years) | Distance travelled in full charge (Km) | Maximum speed (Km/hour) | Energy density (Wh/Kg) | Charging cost/month (Rs) | Number of half trip/day | Distance of each half trip (Km) | Earning /half trip(Rs) |
|---|---|---|---|---|---|---|---|---|---|---|
| 100 | 7150 | 2000 | 2 | 65 | 20 | 42.85 | 2800 | 15 | 2.5 | 55 |
| 130 | 8500 | 2200 | 2.5 | 100 | 28 | 50.32 | 1500 | 15 | 3 | 60 |
| 100 | 7500 | 2000 | 1.5 | 70 | 20 | 42.85 | 1200 | 18 | 3 | 50 |
| 120 | 8500 | 2500 | 1.5 | 85 | 25 | 48 | 1200 | 15 | 3 | 65 |
| 140 | 10000 | 2500 | 2.5 | 110 | 25 | 52.50 | 1500 | 20 | 2.5 | 60 |
| 130 | 9400 | 2500 | 2 | 100 | 25 | 50.32 | 1500 | 15 | 3 | 50 |
| 120 | 8500 | 2500 | 2.5 | 80 | 25 | 48 | 2800 | 15 | 3 | 60 |

TABLE 4.5: Data obtained for toto operating on lead acid battery in Barrackpore

| Power rating(12V), Ah | Cost of new battery (per battery) (Rs) | Resale value (per battery) (Rs) | Life of Battery (years) | Distance travelled in full charge (Km) | Maximum speed (Km/hour) | Energy density (Wh/Kg) | Charging cost/month (Rs) | Number of half trip/day | Distance of each half trip (Km) | Earning /half trip (Rs) |
|---|---|---|---|---|---|---|---|---|---|---|
| 100 | 7250 | 2000 | 2 | 70 | 20 | 42.85 | 1100 | 20 | 3 | 60 |
| 100 | 7200 | 2000 | 2 | 65 | 18 | 42.85 | 1100 | 18 | 3 | 50 |
| 140 | 10000 | 2500 | 2.5 | 110 | 25 | 52.50 | 1500 | 15 | 2.5 | 55 |
| 130 | 8500 | 2200 | 2.5 | 100 | 30 | 50.32 | 1500 | 20 | 3 | 65 |
| 100 | 7200 | 2000 | 1.5 | 70 | 20 | 42.85 | 1100 | 18 | 3 | 50 |
| 120 | 8500 | 2500 | 2 | 85 | 25 | 48 | 3000 | 15 | 3 | 60 |
| 140 | 10000 | 2500 | 2.5 | 110 | 25 | 52.50 | 1500 | 20 | 2.5 | 55 |
| 130 | 9000 | 2500 | 2 | 100 | 25 | 50.32 | 1500 | 15 | 3 | 65 |
| 120 | 8500 | 2500 | 2 | 80 | 25 | 48 | 1100 | 20 | 3 | 60 |
| 100 | 7500 | 2000 | 2 | 70 | 20 | 42.85 | 2500 | 15 | 3 | 55 |

TABLE 4.6: Data obtained for toto operating on lead acid battery in Dhulagarh

| Power rating(12V), Ah | Cost of new battery (per battery) (Rs) | Resale value (per battery) (Rs) | Life of Battery (years) | Distance travelled in full charge (Km) | Maximum speed (Km/hour) | Energy density (Wh/Kg) | Charging cost/month (Rs) | Number of half trip/day | Distance of each half trip (Km) | Earning /half trip (Rs) |
|---|---|---|---|---|---|---|---|---|---|---|
| 100 | 7150 | 2000 | 2 | 65 | 20 | 42.85 | 2800 | 15 | 2.5 | 55 |
| 120 | 8500 | 2500 | 2.5 | 85 | 25 | 48 | 1300 | 15 | 2.5 | 50 |
| 100 | 7150 | 2000 | 1.5 | 65 | 20 | 42.85 | 1500 | 15 | 2.5 | 55 |
| 130 | 9400 | 2500 | 2 | 100 | 25 | 50.32 | 1500 | 18 | 2.5 | 55 |
| 100 | 7200 | 2000 | 2 | 65 | 20 | 42.85 | 1100 | 15 | 2.5 | 60 |
| 140 | 10000 | 2500 | 2.5 | 110 | 25 | 52.50 | 1500 | 20 | 2.5 | 60 |

TABLE 4.7: Data obtained for toto operating on Lithium ion battery in Mukundapur

| Power rating(48V), Ah | Cost of new battery (per battery) (Rs) | Resale value (per battery) (Rs) | Life of Battery (years) | Distance travelled in full charge (Km) | Maximum speed (Km/hour) | Energy density (Wh/Kg) | Charging cost/month (Rs) | Number of half trip/day | Distance of each half trip (Km) | Earning /half trip (Rs) |
|---|---|---|---|---|---|---|---|---|---|---|
| 96 | 105000 | 3250 | 6 | 100 | 30 | 115.2 | 800 | 25 | 2.5 | 65 |
| 76 | 80000 | 2250 | 5 | 80 | 25 | 106.6 | 700 | 25 | 2.5 | 60 |
| 81 | 86000 | 2500 | 5 | 90 | 28 | 108 | 750 | 25 | 2.5 | 55 |
| 72 | 76000 | 2000 | 6 | 70 | 25 | 102.6 | 650 | 20 | 2.5 | 65 |
| 96 | 105000 | 3250 | 6 | 100 | 30 | 115.2 | 800 | 20 | 2.5 | 60 |
| 81 | 86000 | 2000 | 5 | 90 | 28 | 108 | 700 | 22 | 2.5 | 55 |
| 76 | 80000 | 2250 | 5 | 80 | 25 | 106.6 | 800 | 25 | 2.5 | 60 |
| 72 | 76000 | 2000 | 6 | 70 | 25 | 102.6 | 700 | 20 | 2.5 | 50 |
| 76 | 80000 | 2250 | 5 | 80 | 25 | 106.6 | 800 | 25 | 2.5 | 60 |

TABLE 4.8: Data obtained for toto operating on Lithium ion battery in Dumdum

| Power rating(48V), Ah | Cost of new battery (per battery) (Rs) | Resale value (per battery) (Rs) | Life of Battery (years) | Distance travelled in full charge (km) | Maximum speed (Km/hour) | Energy density (Wh/Kg) | Charging cost/month (Rs) | Number of half trip/day | Distance of each half trip (Km) | Earning /half trip (Rs) |
|---|---|---|---|---|---|---|---|---|---|---|
| 81 | 86000 | 2000 | 5 | 90 | 28 | 108 | 750 | 20 | 2.5 | 65 |
| 96 | 105000 | 3250 | 6 | 100 | 30 | 115.2 | 800 | 25 | 2.5 | 60 |
| 81 | 86000 | 2000 | 5 | 90 | 28 | 108 | 700 | 25 | 2.5 | 55 |
| 76 | 80000 | 2250 | 5 | 80 | 25 | 106.6 | 700 | 25 | 2.5 | 60 |
| 72 | 76000 | 2000 | 6 | 70 | 25 | 102.6 | 600 | 20 | 3 | 50 |
| 76 | 80000 | 2250 | 5 | 80 | 25 | 106.6 | 800 | 20 | 2.5 | 60 |

TABLE 4.9: Data obtained for toto operating on Lithium ion battery in Barrackpore

| Power rating(48V), Ah | Cost of new battery (per battery) (Rs) | Resale value (per battery) (Rs) | Life of Battery (years) | Distance travelled in full charge (Km) | Maximum speed (Km/hour) | Energy density (Wh/Kg) | Charging cost/month (Rs) | Number of half trip/day | Distance of each half trip (Km) | Earning /half trip (Rs) |
|---|---|---|---|---|---|---|---|---|---|---|
| 96 | 105000 | 3250 | 6 | 100 | 30 | 115.2 | 800 | 30 | 2.5 | 60 |
| 72 | 76000 | 2000 | 6 | 70 | 25 | 102.6 | 600 | 20 | 2.5 | 55 |
| 76 | 80000 | 2250 | 5 | 80 | 25 | 106.6 | 700 | 25 | 2.5 | 60 |
| 76 | 80000 | 2250 | 6 | 80 | 25 | 106.6 | 800 | 20 | 2.5 | 55 |
| 81 | 86000 | 2000 | 5 | 90 | 28 | 108 | 700 | 25 | 2.5 | 65 |
| 76 | 80000 | 2250 | 5 | 80 | 25 | 106.6 | 750 | 20 | 2.5 | 50 |

# 4.1Comparative Analysis

## 4.1.1 Energy density

Energy density refers to the amount of energy stored in a battery per unit volume or mass. It has been observed at the table given and take the average of energy density calculated for both Lithium ion and lead acid battery separately than comparative graph can be drawn for both batteries as drawn below in figure 4.1 and can make the analysis as follow:

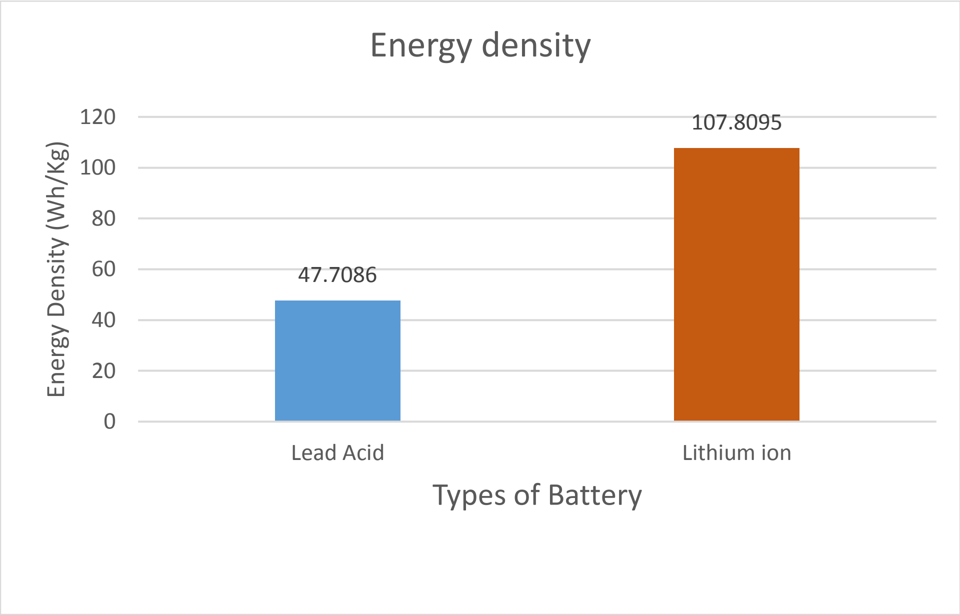


Figure 4.1: Comparison of energy density

Lithium-ion batteries have a high energy density which is 107.8095 wh/kg than that of a lead acid batteries which has energy density equals to 47.7086 as observed in the above figure 4.1. The actual energy density can vary depending on factors such as battery size, construction, and manufacturer.

Comparing the two battery types, Lithium-ion batteries have a significantly higher energy density compared to lead-acid batteries. This means that for the same weight or volume, Lithium-ion batteries can store more energy, making them more compact and lightweight. Consequently, Lithium-ion batteries are widely used in portable electronic devices, electric vehicles (EVs), and renewable energy systems where high energy density is crucial. Lead-acid batteries, although having lower energy density, are still used in various applications due to their lower cost, reliability, and ability to provide high currents. They are commonly used in traditional vehicles, backup power systems, and some stationary applications where weight and size are less critical factors.

### 4.1.2 Life Cycle analysis

Life cycle analysis refers to the number of charge and discharge cycles a battery can undergo before its capacity significantly degrades. Figure 4.2 shows the battery life for lead and Lithium ion batteries as obtained from the survey data.

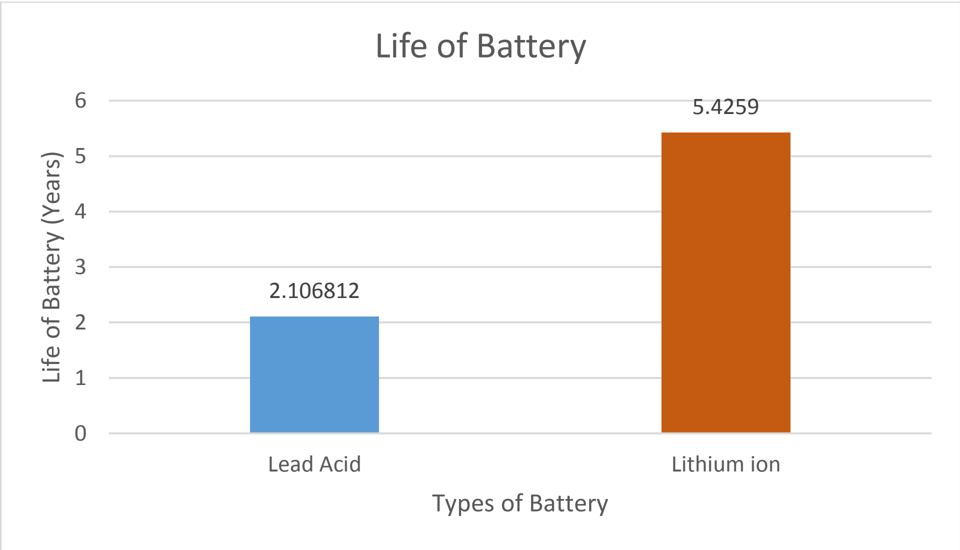


Figure 4.2: Comparison of life of the battery in years

Lithium-ion batteries generally offer a higher life compared to lead-acid batteries. It can be observed from the above graph shown in figure 4.2 that lead acid has a life of 2.106812 years while that of a Lithium ion battery has life of 5.4259 years. Depending on the specific chemistry, Li-ion batteries can typically provide between 500 to 1,500 cycles before their capacity drops to around 80% of the original capacity [21]. Some advanced Li-ion chemistries can even exceed 3,000 cycles. In terms of years Lithium ion batteries can be used up to 5 to 6 years. Standard lead-acid batteries can provide around 200 to 500 cycles before their capacity degrades to about 80% of the original capacity [23]. In terms of years, lead acid battery has a life of 1 year to 3 years depending upon the energy capacity of the battery.

In terms of life cycle, Lithium-ion batteries have a clear advantage over lead-acid batteries. The longer cycle life of Li-ion batteries makes them more suitable for applications that require frequent charge and discharge cycles, such as electric vehicles (EVs) and energy storage systems. Additionally, Li-ion batteries tend to maintain a more consistent capacity over their lifetime compared to lead-acid batteries.

### 4.1.3 Charging time

Lithium-ion batteries are known for their relatively shorter charging time compared to lead-acid batteries. Generally, Li-ion batteries can be charged to their full capacity within a few hours, typically ranging from 1 to 4 hours. However, fast charging techniques and infrastructure advancements are being developed, enabling even faster charging times.

Lead-acid batteries typically have a longer charging time compared to Li-ion batteries. In general, lead-acid batteries require a longer charging time, often ranging from 8 to 12 hours or more to fully charge.

The charging time can be influenced by factors such as battery capacity, charging rate, and the state of charge of the battery. Additionally, the charging infrastructure for Li-ion batteries, especially in the context of electric vehicles, is more developed and widespread. This allows for more convenient and accessible charging options for Li-ion batteries.

### 4.1.4 Cost comparison and economic viability

The cost comparison between lead-acid and Lithium-ion batteries used in toto can vary depending on various factors such as the specific battery models, manufacturing costs, market conditions, and economies of scale. Li-ion batteries have had a higher upfront cost compared to lead-acid batteries as observed from the data collected in above tables. However, over the years, advancements in manufacturing processes, economies of scale, and increased demand have led to a significant reduction in the cost of Li-ion batteries. While the cost can vary depending on factors like capacity, chemistry, and manufacturer, Li-ion batteries are becoming increasingly competitive in terms of cost. The cost of Li-ion batteries is expected to continue declining as technology advancements and production efficiencies progress.

Lead-acid batteries are generally less expensive upfront compared to Li-ion batteries. They have been available in the market for a longer time, and their manufacturing processes are more established, which contributes to their lower cost. However, it's important to note that additional costs may arise due to the need for maintenance, replacement, and potential disposal of lead-acid batteries.

### 4.1.4.1 Energy cost per passenger per kilometer:

The energy cost per passenger per km as obtained from the calculation mentioned in appendix and has been shown in the figure 4.3. From the graph it can be observed that the energy cost per passenger per km is maximum at Mukundapur for lead acid battery and minimum at Barrackpore while for the Lithium ion battery data has been collected only at 3 locations with maximum at Mukundapur and minimum at Barrackpore.

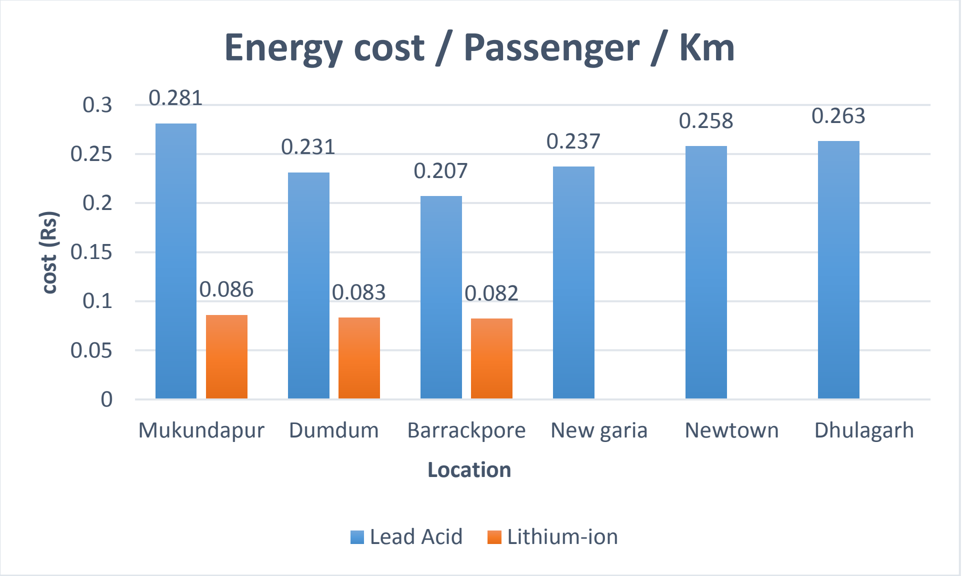


Figure 4.3: comparison chart of energy cost /passenger /Km

On comparing both batteries used in toto at different location in Kolkata it was observed that the energy cost per passenger per kilometer would typically be lower for Lithium-ion batteries compared to lead-acid batteries, same we can see from the above graph shown in figure 4.3 also. Lithium-ion batteries provide higher energy density compared to that of lead acid battery therefore can be more feasible for the drivers in the longer run of the vehicle.

### 4.1.4.2 Total Expenditure per Passenger per kilometer:

The total expenditure per passenger per km as obtained from the calculation mentioned in appendix and has been shown in the figure 4.4. From the graph it was observed that the total expenditure per passenger per km is maximum at Dhulagarh for lead acid battery and minimum at Barrackpore while for the Lithium ion battery data has been collected only at 3 locations with maximum at Mukundapur and minimum at Barrackpore.

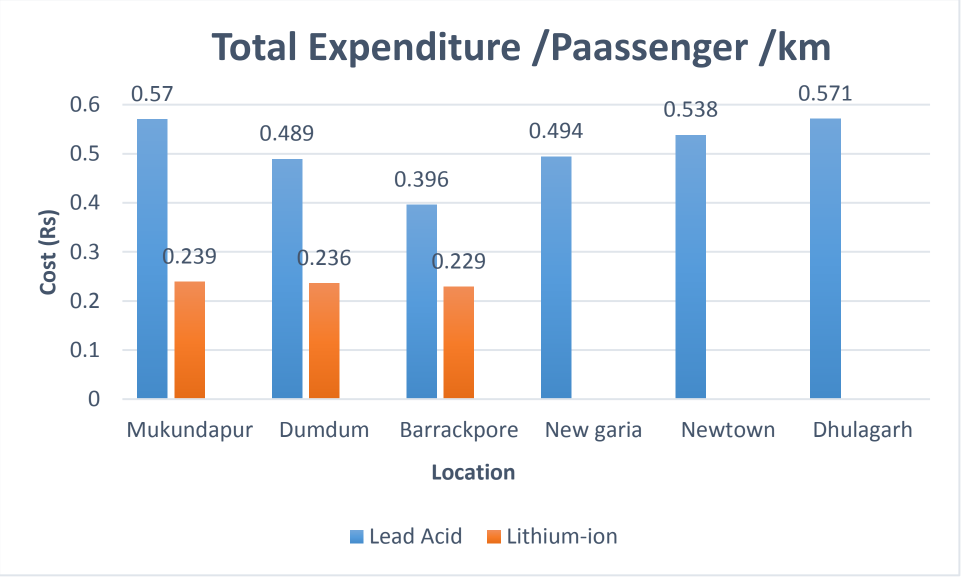


Figure 4.4: Comparison chart of total expenditure /passenger /Km

On comparing both batteries used in toto at different location in Kolkata it was observed find that the total expenditure per passenger per kilometer is lower for Lithium ion batteries than that of Lead acid batteries. It is due to lower operational cost, higher efficiency and higher life cycle of Lithium ion batteries compared to lead acid batteries.

It has been observed at the expenditure incurred by different sectors on the battery, found that the maximum expenditure for lead acid battery is gone under electricity charges as shown in figure 4.5 while for the Lithium ion battery maximum expenditure done under the purchase of the new battery as shown in figure 4.6. As the initial cost of Lithium ion battery is high compared to lead acid battery which has lower initial cost and the electricity charges for lead acid battery is high compared to Lithium ion battery as lead acid battery consume more energy to get fully charged. Expenditure occurred in different sectors such as charging cost of battery, maintenance cost, cost of distilled water in lead acid battery, purchasing cost of battery is shown in pie chart drawn below. It can be observed that how much percentage of total expenditure done on battery comes from different sectors. This will help us analyse, expenditure on which sector we have to reduce to earn the maximum profit. For Lithium ion battery there is no such maintenance cost as done in lead acid battery.

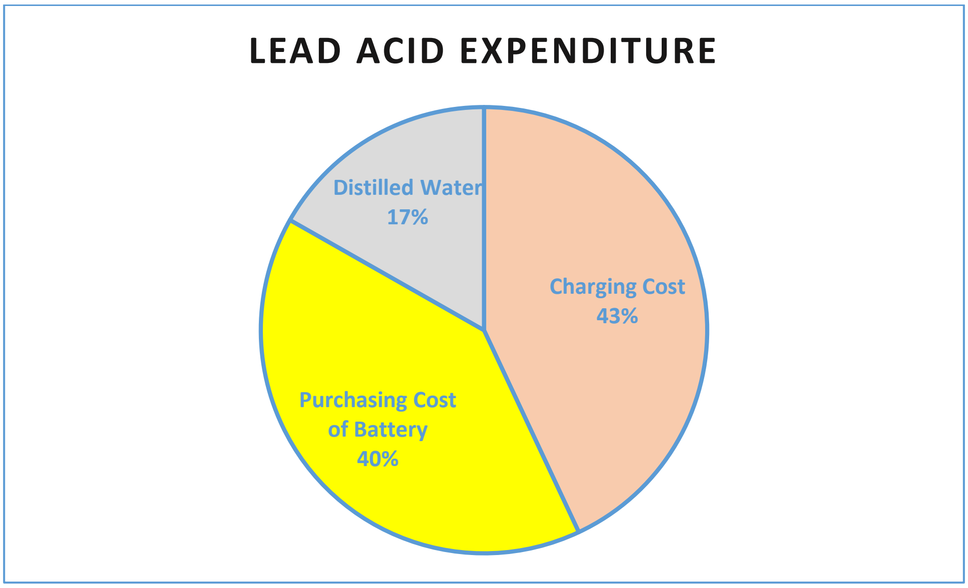


Figure 4.5: Lead acid expenditure

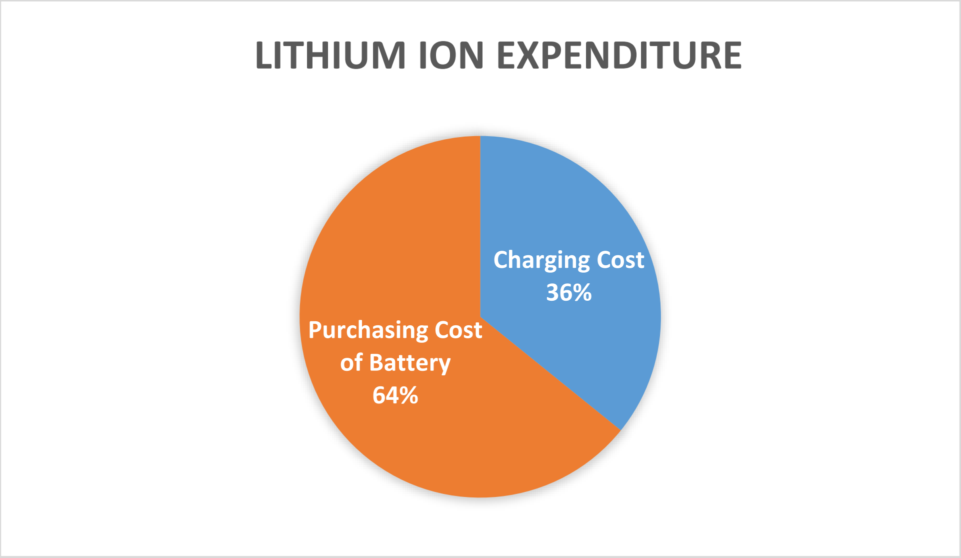


Figure 4.6: Lithium ion expenditure

### 4.1.5 Economic Viability:

The earning per month as obtained from the calculation mentioned in appendix and has been shown in the figure 4.7. From the graph it was observed that the earning per month of the driver is maximum at New Garia for lead acid battery and minimum at Dhulagarh while for the Lithium ion battery data has been collected only at 3 locations with maximum at Mukundapur and minimum at Dumdum.

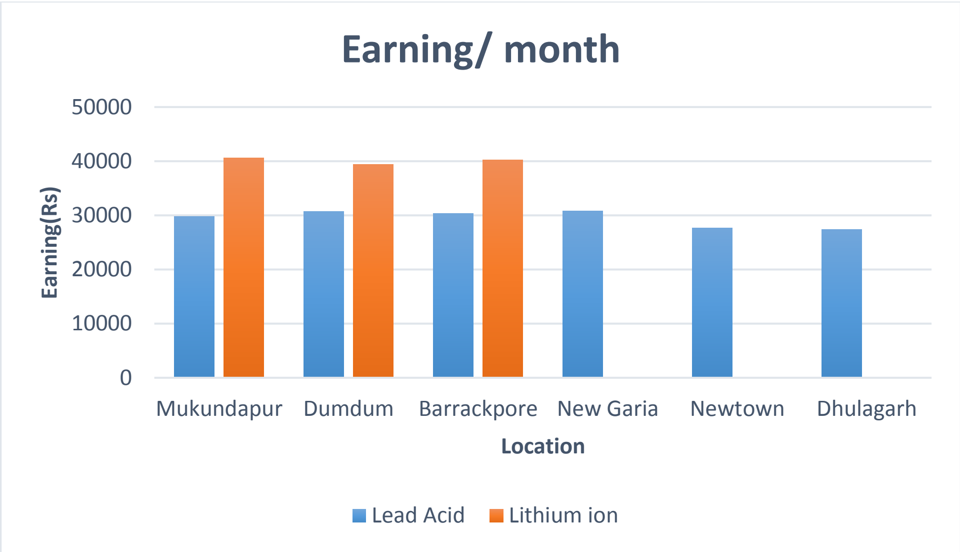


Figure 4.7: Comparison chart of earning of owner from toto

With all the benefits of Lithium ion battery over lead acid battery, drivers operating toto with Lithium ion battery earns more than that of the toto with lead acid battery as we can see from the graph of earning of driver of toto with both batteries at different locations in Kolkata. Li-ion batteries have seen significant cost reductions and are becoming increasingly economically viable across various applications. However, lead-acid batteries continue to be economically viable in certain use cases, especially where cost is a primary consideration as the initial cost of lead acid battery is less.

### 4.1.6 Environmental impact

When we charge the battery with electricity, the amount of units consumed of electricity is produced in thermal powerplant producing lot of pollutants into the environment such as $CO_2$, $SO_2$, NO etc. which I have calculated using the data collected from the drivers of toto. Also, Lead-acid batteries have certain environmental impacts and sustainability considerations due to the materials used in their construction and the potential for improper disposal. The CO2, SO2 and NO emitted per passenger per km as obtained from the calculation mentioned in appendix and has been shown in the figure 4.8, figure 4.9 and figure 4.10 respectively. From the graph it has been observed that the $CO_2$ emitted per passenger per km, $SO_2$ emitted per passenger per km and NO emitted per passenger per km is maximum at Mukundapur for lead acid battery and minimum at Barrackpore while for the Lithium ion battery data has been collected only at 3 locations with maximum at Mukundapur and minimum at Barrackpore.

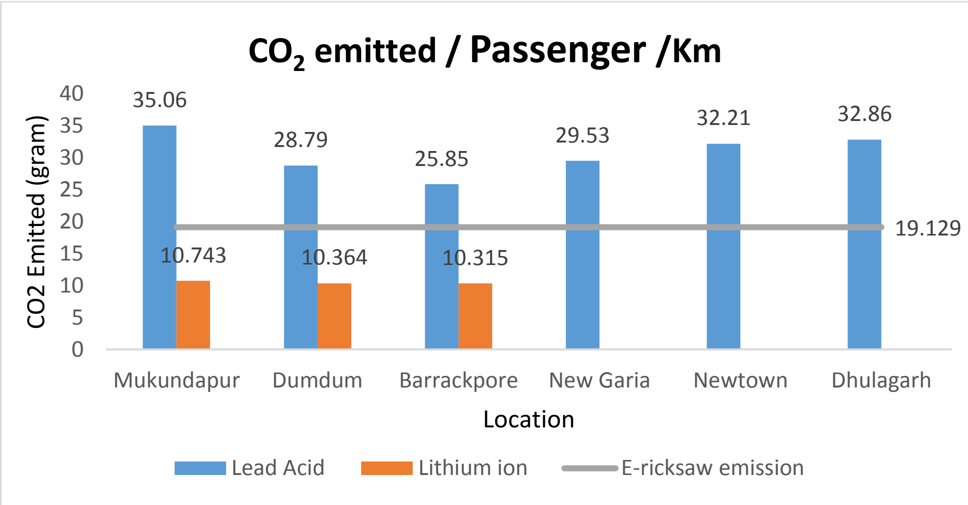


Figure 4.8: Comparison chart of $CO_2$ emission from plant

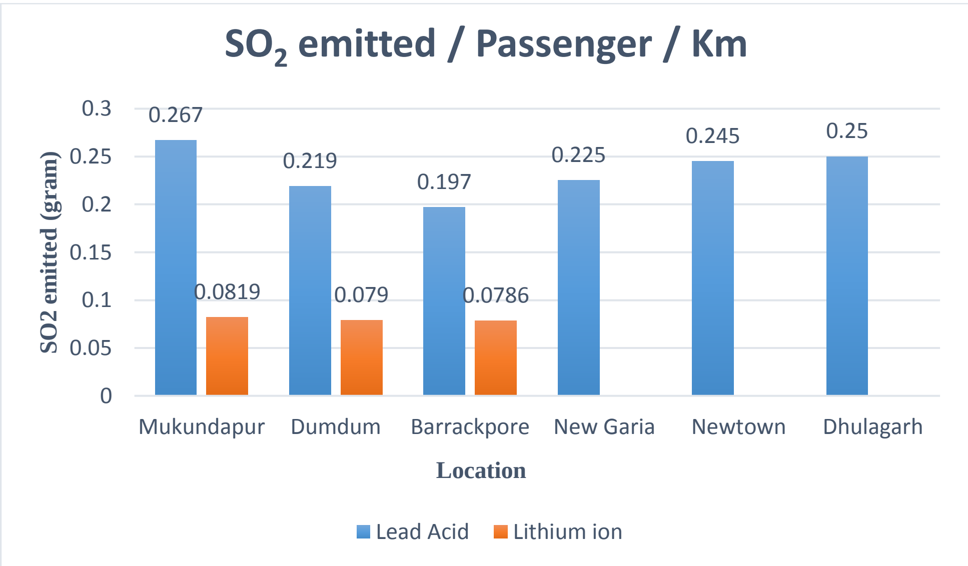


Figure 4.9: Comparison chart of $SO_2$ emission from plant

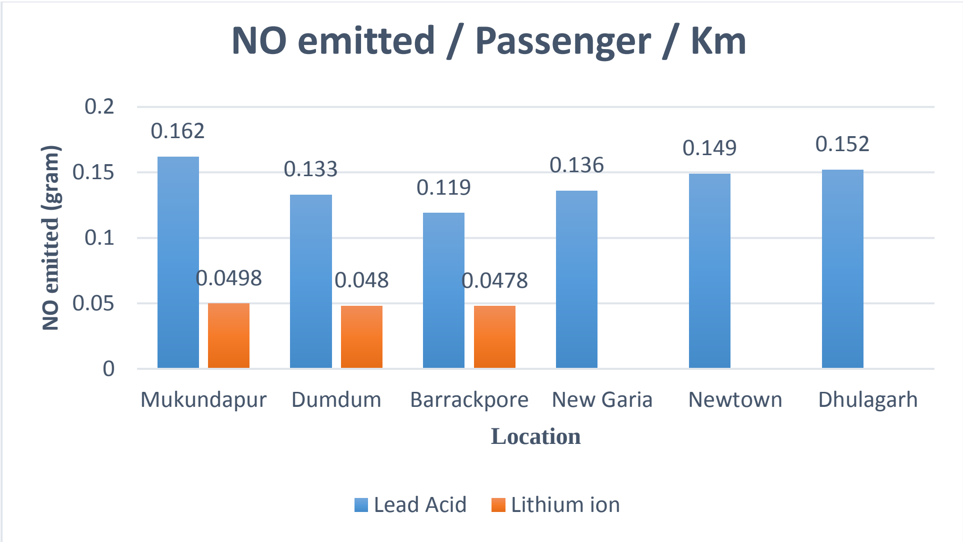


Figure 4.10: Comparison chart of NO emission from plant

It has been observed from the above graph that $CO_2$, $SO_2$, NO all three are emitted more for the lead acid batteries than that of Lithium ion battery from the thermal power plant. As lead acid battery also takes more time to get fully charged therefore consumes more energy hence in turn produces more amount of pollutant from the powerplant. We compared the CO2 emission from charging of toto battery with one of the research paper published [1] and found that if we take the average of emission from lead acid and Lithium ion battery it comes near to the emission calculated for the e-ricksaw in the paper i.e 19.129 gram/passenger /km of $CO_2$[1].

### 4.1.7 Payback period

Payback period refers to the amount of time it takes to recover the cost of an investment i.e. Battery cost and cost of the toto. It is the length of time an investment reaches a breakeven point. The payback period of batteries is length of time it takes for the savings or benefits generated by a battery system to equal or surpass the initial investment or cost of the batteries. The payback period varies depending on factors such as the cost of the batteries, energy savings or revenue generated by the batteries, and the specific application or industry. Payback period of the battery obtained from the calculation mentioned in appendix has been shown in figure 4.11. It has been also calculated the payback period of the battery by taking in to account the personal expenses per month of the driver as Rs.10000 for low end expenses, Rs.15000 for medium end expenses and Rs.20000 for high end expenses of the drivers then, It has been observed from the trendline how the payback period is changing according to the personal expense has been shown below in figure 4.15.

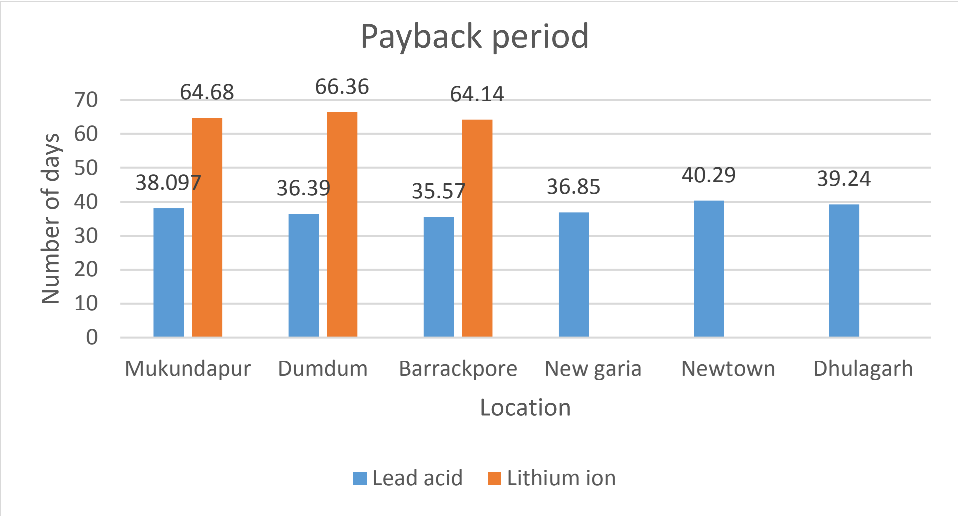


Figure 4.11: Payback period of battery with no personal expense

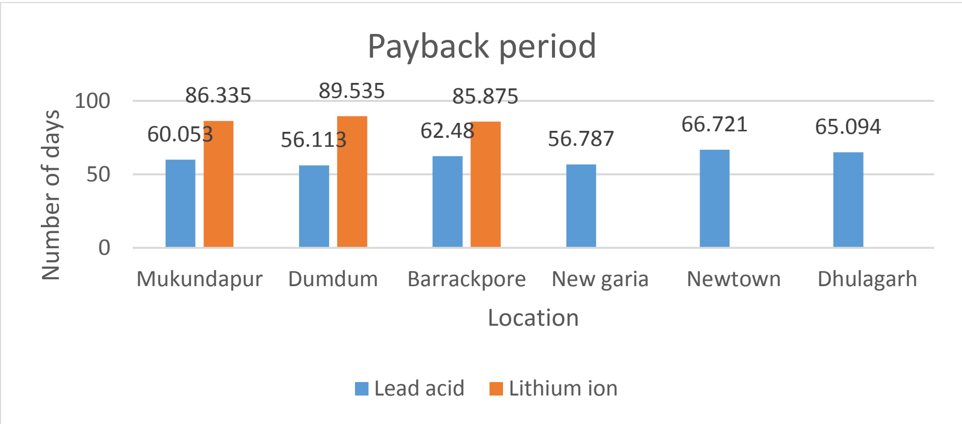


Figure 4.12: Payback period of battery with personal expense of Rs 10000/month

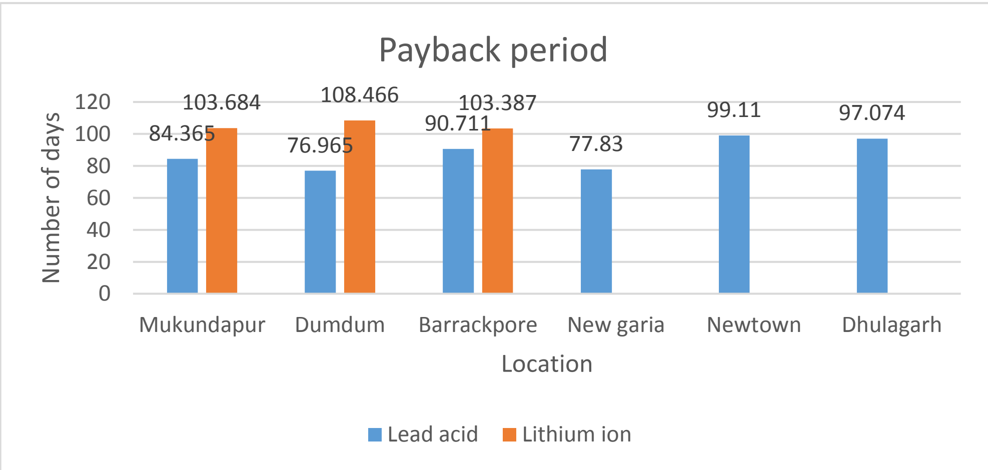


Figure 4.13: Payback period of battery with personal expense of Rs 15000/month

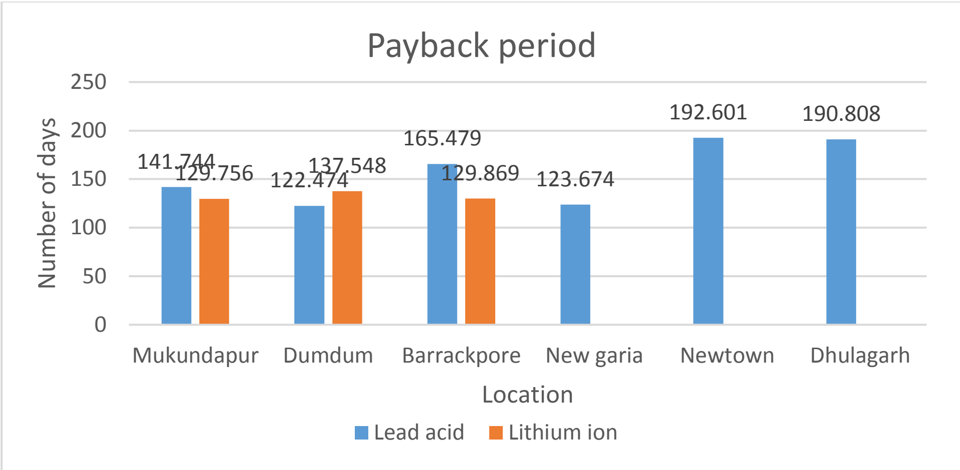


Figure 4.14: Payback period of battery with personal expense of Rs 20000/month

It has been observed from the trendline that how the payback period is changing with personal expense as shown in figure 4.15.

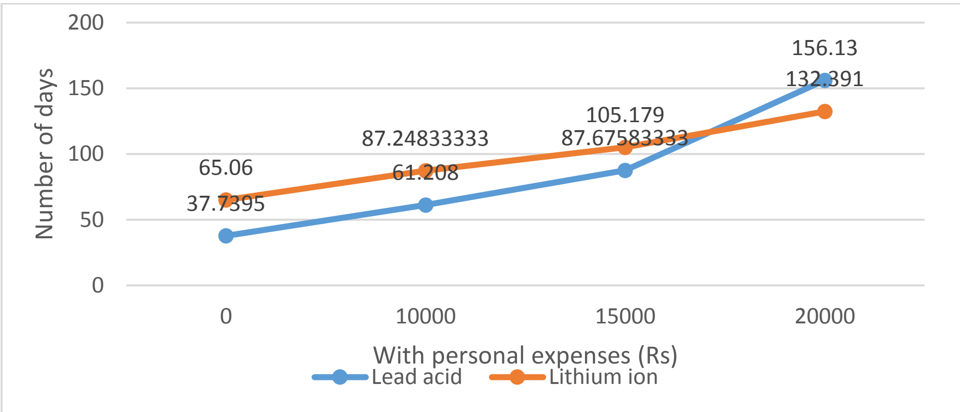


Figure 4.15: Payback period of battery with  varying personal expense

It was observed from the graph that payback period for the lead acid battery is lower than that of the Lithium ion battery because ,the initial cost of Lithium ion battery is high comapred to lead acid battery. Also, as the personal expenses of  driver is incresing the payback period also increases for both th batteries. When the personal expense is Rs.20000 payback period for Lithium ionbattery is lower than that of lead acid battery as the daily earning from Lithium ion battery is also higher than that of lead acid battery therfore net earning becomes very less with expense of Rs.20000 for leadacid battery. But the higher efficiency and longer cycle life of Lithium-ion batteries may contribute to cost savings over time which is not same in case of lead acid battery. The shorter cycle life and lower efficiency of lead-acid batteries may impact the payback period, as they may require more frequent replacements and result in higher operational and maintenance costs. We can also see from the below graph the break even point for both lead acid and Lithium ion batteries. The breakeven point typically represents the point in time when the savings or benefits from using the batteries offset the initial investment and ongoing costs. The breakeven point occurs when the cumulative savings or benefits equal the initial investment and ongoing costs. This calculation provides an estimate of the time required to recover the investment and start generating a positive return. Here we can see the break even point for toto using lead acid and Lithium ion batteries. It takeslesser time for toto using lead acid battery to recover its initial investment as its initial investment plus ongoing is less ascompared to Lithium ion batteries. After the break even point the owner of the vehicle starts earning profit. This breakeven point is the minimum time period after which the owner of the vehicle wil start erning actual profit. The break even point for both lead acid battery and Lithium ion battery with no personal expenses has been shown below in figure 4.16 and figure 4.17 respectively As the personal expense of the driver will increase, it will take more number of days for them to start earning profit.

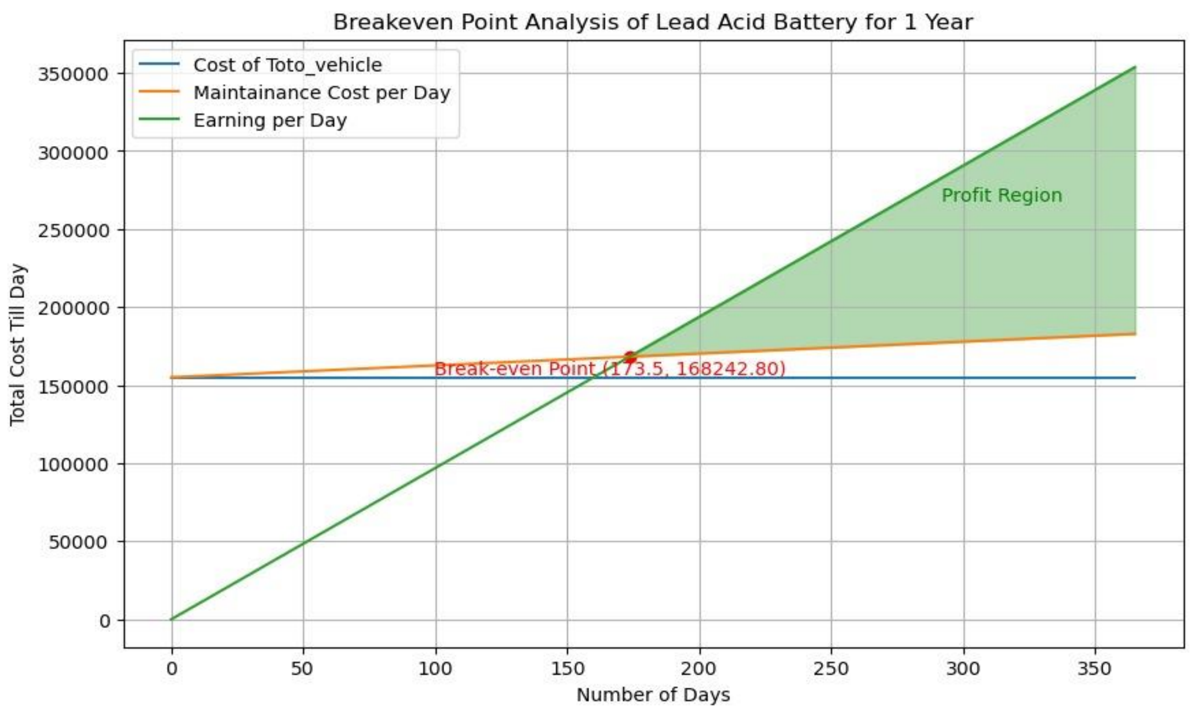


Figure 4.16: Breakeven point analysis of lead acid battery

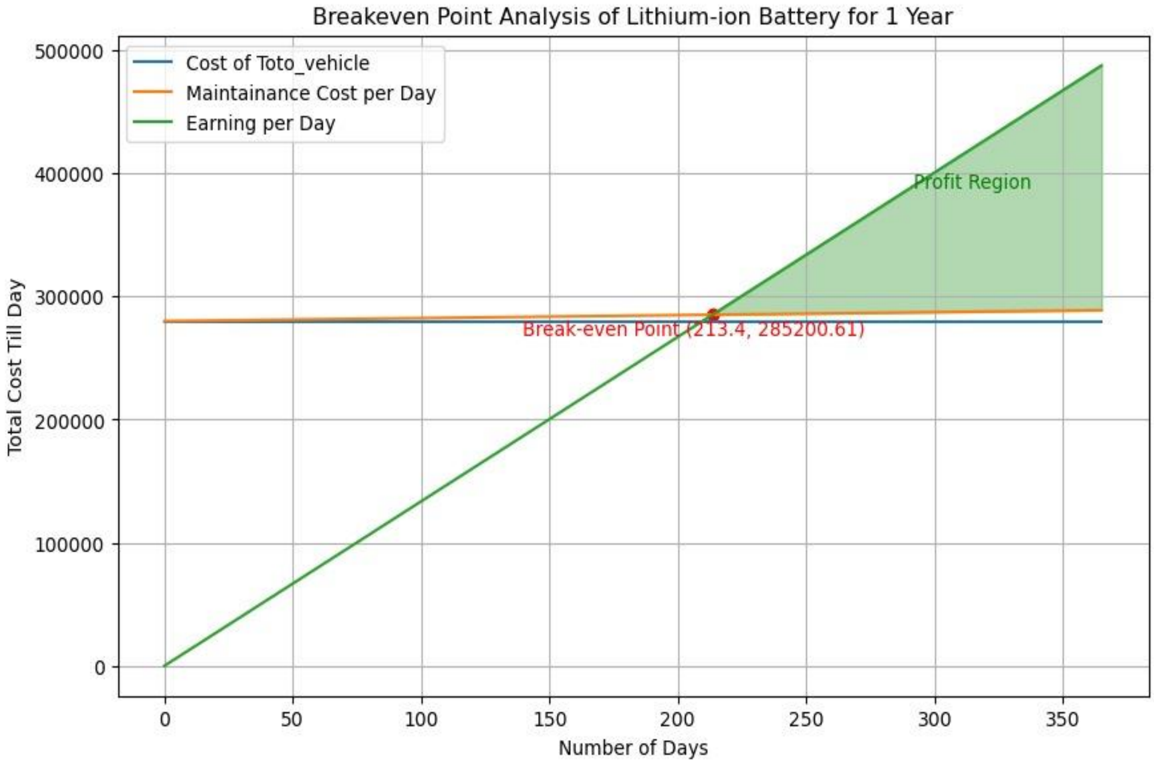


Figure 4.17: Breakeven point analysis of Lithium ion battery

### 4.1.8 Recycling of Battery

**Li-ion Batteries**: Li-ion batteries can be recycled to recover valuable materials like Lithium, cobalt, and nickel. Proper recycling processes are essential to minimize environmental impacts and to ensure the safe handling and disposal of battery waste. The recycling infrastructure for Li-ion batteries is still developing in some regions, and challenges remain in effectively managing the increasing volume of Li-ion battery waste. Li-ion batteries are complex products, many paths for their recycling are possible. Some of these paths, starting after the pack has been dismantled, which shows the interrelationships among process types. There are three basic process types: pyrometallurgy (smelting), hydrometallurgy (leaching), and direct recycling (physical processes). Process components can be combined in different ways, depending on factors like quantity and characteristics of the material available and quantity and value of the materials that can be recovered.

Pyrometallurgy uses high temperature to facilitate the oxidation and reduction reactions in which transition metals like Co and Ni are reduced from oxides to metals, and recovered in a mixed metal alloy. this leaves powder of nickel cobalt alloy which is then treate chemically. The metals can then be separated (by hydrometallurgy) and used to make new cathode material. Other materials, including the aluminum, anode, and electrolyte, are oxidized in the smelter, supplying much of the process energy. The aluminum and Lithium oxides end up in the slag and are not generally recovered. One key advantage is that pyro process avoid shredding and dismantling phase.

Hydrometallurgy uses acids to dissolve the ions out of a solid like the cathode, producing a mixture of ionic species in solution. The hydro process involves mechanical treatment for shredding and disassembling batteries. After that they put into an acid solution for separation of elements. Even if the liquid solution is directly usable for nickel cobalt sulfate and even if the separatability is difficult due to their similar physical properties some amount of Lithium and copper is lost. These can be recovered by precipitation or solvent extraction and reacted with other recovered materials to produce new cathode material. Other techniques like membrane separation have been proposed. Direct recycling separates the different components of the black mass by physical processes, like gravity separation, which recover separated materials without causing chemical changes, enabling recovery of cathode material that is reusable with minimal treatment.

Figure 4.18: Lithium ion battery recycling plant

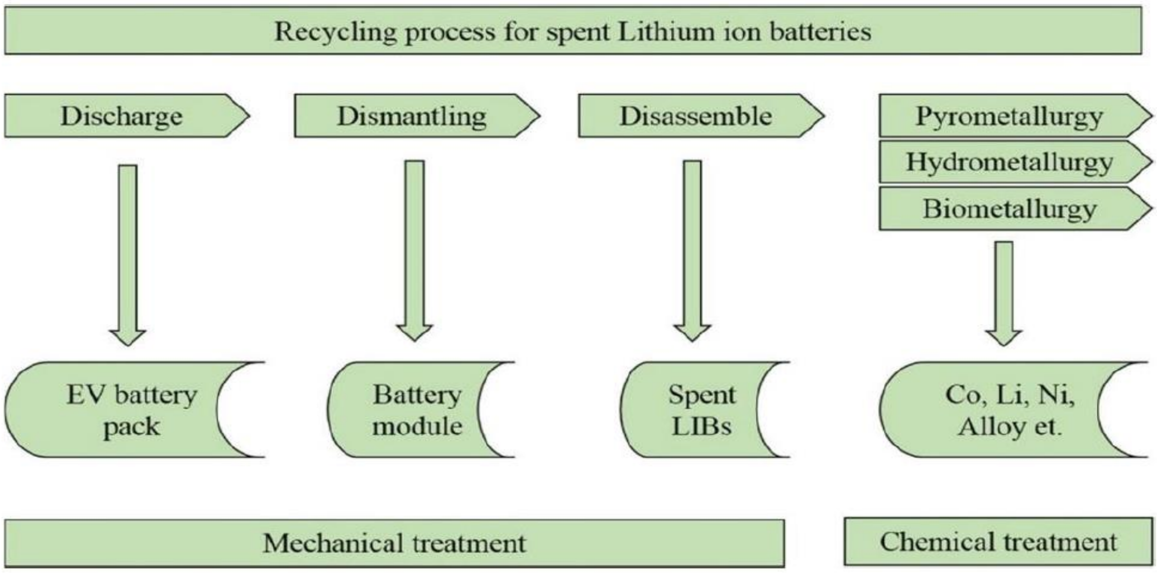


Figure 4.19: Flowchart of Recycling process of spent Lithium ion batteries

**Lead-Acid Batteries**:

Lead-acid batteries are highly recyclable, and the recycling infrastructure for them is well-established in many regions. The recycling process involves recovering lead and other materials, reducing the need for primary lead production. Adequate recycling practices are crucial to prevent lead contamination and environmental harm. Lead recovery from spent accumulators can take two basic routes. Either the components of an accumulators like lead, plastics, acids, etc. are at first separated and then processed individually, or the acid is extracted first and the batteries are processed as a whole. In the first case, recycling materials are recovered from all components of a battery. In the second case, only lead is recovered (partially also residual battery acid), whereby organic components are consigned to energy recycling. In view of the high pollution control standards implemented in secondary lead smelters of industrialised countries, modern lead recycling does not pose a significant health hazard to the local population or the environment. The battery contains 70% lead, 20% acid and 10% plastic case [16]. In recycling process batteries are broken cover of batteries is removed and acid is drained out for neutralization. Top portion is hammered for shredding of plastic and the lead posts fixed in the top are released. Furnace smelting is done for approximately 5 hours at over 1000$^{o}$C lead [16] and slag is tapped separately as shown in figure 4.21. Refining is done by lowering the temperature thereby decreasing the solubility of impurities. Once the lead is purified it is cast into ingots and reused for further purposes. But during this process lead dust and toxic gases released which needs proper filtering. To arrest these dust particles bag filter or filter fabric can be used to collect dust particles. Recycled lead from the lead acid batteries can be again used for in the new lead acid batteries in this way we can reduce the dependence for the extraction of new lead which will also reduce the impact on environment.

Figure 4.20: Hammering of lead acid battery

Figure 4.21: Furnace for smelting

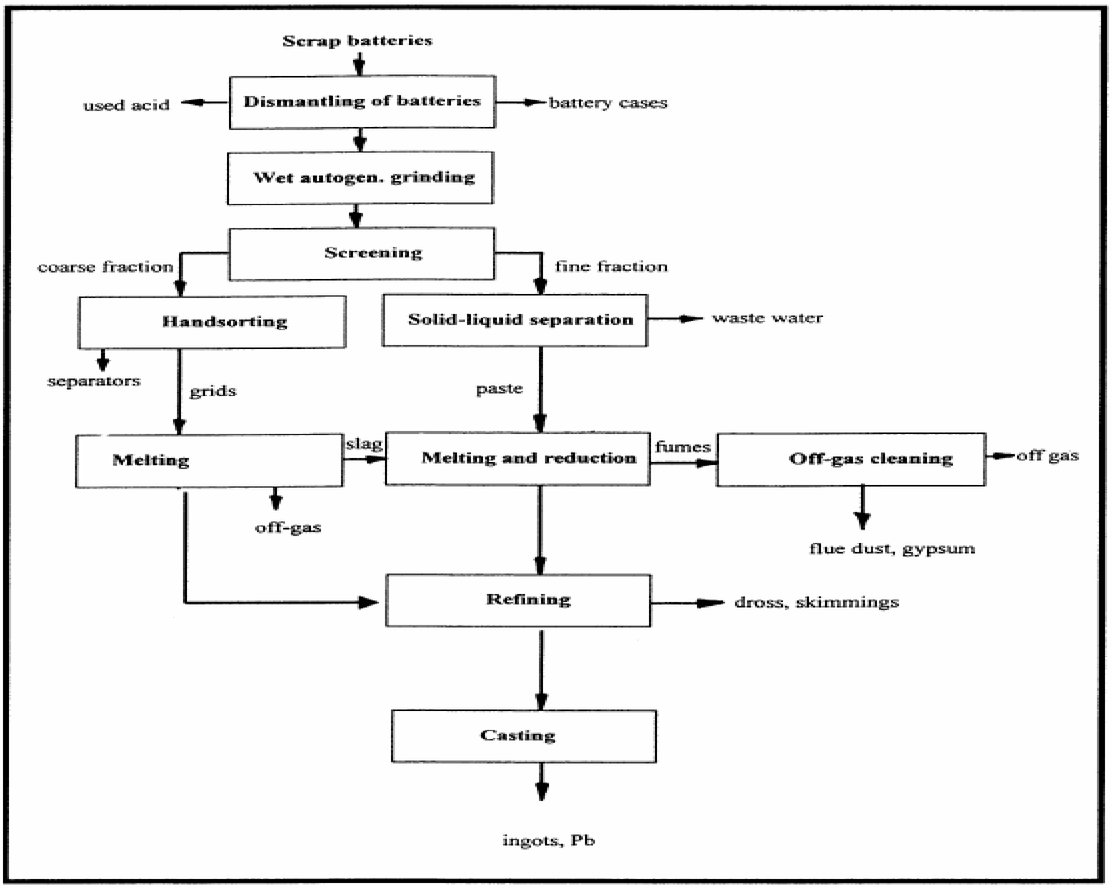


Figure 4.22: Flowchart of Recycling process of spent lead acid batteries

Figure 4.23: Smelting in furnace for lead acid battery at Dhaulagarh, Kolkata

Both Li-ion and lead-acid batteries have environmental impacts associated with their lifecycle, from resource extraction and manufacturing to use and disposal. However, Li-ion batteries generally have a lower environmental impact due to higher energy efficiency, lower emissions, and the potential for valuable material recovery through recycling. Proper management of battery waste and the development of robust recycling infrastructure are important for mitigating the environmental impact of both battery types.

# Chapter-5

# Conclusion

## 5.1 Conclusion

A comparative analysis of lead-acid and Lithium-ion batteries used in toto reveals several key findings:

- Energy Density: Lithium-ion batteries have a significantly higher energy density (107.8095 Wh/Kg) compared to lead-acid batteries (47.7086 Wh/Kg). This means that Lithium-ion batteries can store more energy per unit volume or weight, resulting in a longer driving range for toto.
- Weight: Lead-acid batteries are considerably heavier than Lithium-ion batteries for the same energy capacity. This weight difference affects the overall weight of the toto, impacting its efficiency and handling.
- Charging Time: Lithium-ion batteries have a shorter charging time compared to lead-acid batteries. This is due to the higher charge acceptance rate and efficiency of Lithium-ion batteries. Faster charging times can result in reduced downtime for toto and increased productivity.
- Cycle Life: Lithium-ion batteries generally have a longer life (5.4259 years) compared to lead-acid batteries (2.106812 years). A cycle refers to one complete charge-discharge cycle. The extended cycle life of Lithium-ion batteries means they can withstand a larger number of charge-discharge cycles before experiencing a significant decline in performance.
- Maintenance: Lead-acid batteries require regular maintenance, including checking and topping up electrolyte levels, cleaning terminals, changing distilled water and equalizing charges. Lithium-ion batteries, on the other hand, are virtually maintenance-free, reducing the overall maintenance costs and effort.
- Environmental Impact: Lead-acid batteries contain toxic lead and sulfuric acid, making them more environmentally hazardous compared to Lithium-ion batteries. Lead acid battery due to charging it also produces more amount of $CO_2$, $SO_2$ and NO from the power plant due to the consumption of electricity for charging than that of Lithium ion batteries. Lithium-ion batteries are generally considered more

environmentally friendly due to their lower environmental impact during production, use, and disposal.

- Cost: Lead-acid batteries are typically cheaper than Lithium-ion batteries upfront. However, the total cost of ownership over the battery's lifespan, considering factors like cycle life and maintenance, needs to be taken into account. In some cases, the higher upfront cost of Lithium-ion batteries can be offset by their longer lifespan and better performance. Lead acid battery also have their resale value after theiruse but Lithium ion battery has very less resale value compared to their original price of purchase.
- Lead acid battery has also higher energy cost/passenger/Km and total expenditure /passenger /Km than that of Lithium ion batteries. Which makes Lithium ion battery more suitable for the owner of toto.
- Payback period for toto with lead acid battery is 173.5 days which is less compared to that of toto with Lithium ion battery (213.4 days) as the initial cost of toto with Lithium ion battery is higher compared to toto with lead acid battery as Lithium ion battery is costly than lead acid battery. Owner of toto with lead acid battery will start earning profit early but not for the the longer duration whereas owner of toto with Lithium ion will start earning profit late but for very longer duration, hence Lithium ion battery is more profitable for the owner.

Based on these findings, Lithium-ion batteries offer several advantages over lead-acid batteries for toto, including higher energy density, lighter weight, shorter charging time, longer cycle life, lower maintenance requirements, and reduced environmental impact. However, the cost aspect should be carefully considered based on specific requirements and budget constraints. It was observed that Lithium ion battery is more profitable for the owner in the longer run but due to its higher initial cost of investment many people do not prefer it. Lead acid battery has lower initial cost and easily available in market and also distance covered with one full charge of lead acid battery is sufficient to cover the daily trip of the driver that’s why it is more preferred but with changing technology in near future if Lithium ion battery will get cheaper and comparable to lead acid battery then with all the benifits over lead acid battery, will become a  preferred option for the owner. In Kolkata currently people are preferring more lead acid batteries due to its low initial cost, easy availability and better maintenance facilities available for this type of battery.

## 5.2 Scope of Future Work

Future directions for research and development for lead-acid and Lithium-ion batteries used in toto could include the following areas:

- Energy Density Improvement: Researchers could focus on enhancing the energy density of lead-acid batteries to make them more competitive with Lithium-ion batteries. This could involve exploring advanced electrode materials, electrolyte formulations, and new cell designs to increase energy storage capacity.
- Performance and Lifespan Enhancement: Efforts could be directed towards improving the performance and lifespan of Lithium-ion batteries. This could involve research into optimizing electrode materials, electrolyte stability, and cell designs to enhance cycle life, reduce capacity degradation, and increase overall battery efficiency.
- Charging Infrastructure Development: As toto continue to gain popularity, developing a robust and efficient charging infrastructure becomes crucial. Research could focus on designing fast-charging solutions, standardizing charging protocols, and exploring advanced charging technologies such as wireless charging to enhance the charging experience for toto owners and operators.
- Safety Enhancements: Battery safety is a critical concern, particularly in high-demand applications like toto. Future research could aim to develop advanced safety features, such as improved thermal management systems, enhanced fault detection mechanisms, and better fire prevention measures, to ensure the safe operation of both lead-acid and Lithium-ion batteries.
- Environmental Sustainability: Efforts can be directed towards making both lead-acid and Lithium-ion batteries more environmentally friendly. This may involve exploring greener materials, developing recycling processes to recover valuable materials from used batteries, and minimizing the environmental impact of battery manufacturing and disposal.
- Cost Reduction: Research and development can focus on reducing the cost of both lead-acid and Lithium-ion batteries. This could involve exploring new manufacturing techniques, improving production efficiency, and finding cost-effective alternatives for critical battery components.

- Hybrid Solutions: Another direction for research could involve developing hybrid battery systems that combine the strengths of lead-acid and Lithium-ion technologies. This could lead to improved overall performance, cost-effectiveness, and reliability in toto applications.

# Chapter-6

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# Chapter-7

# Appendix

## 7.1 Calculations

**For Lead Acid Battery**

1. **Mukundapur**

Charging cost /month = Rs. 1888.88

Total charging cost in its Lifetime = 1888.88*12*2.11 = Rs.47826.441

Cost of Distilled water / week = Rs. 130

Total cost of distilled water in its lifetime = 130*52*2.11 = Rs.14263.60

Number of Passenger /Half trip = 5

Number of half trip/Day = 17.88

Distance of each Half trip = 2.5Km

Life of Battery = 2.11 Years

Number of Km in Lifetime = 17.88*30*2.5*12*2.11 = 33954.12 Km

Energy cost / Passenger / Km = $\frac{47826.441}{5*33954.12}$ = Rs. 0.281 / Passenger / Km

Cost of New Battery = Rs. 8683.33

Total number of Battery = 4

Total cost of Battery = 4*8683.33 = Rs.34733.32

Resale value of Battery = Rs.2344.44

Total Expenditure = 47826.441 + 34733.32 + 14263.60 = Rs.96823.361

Total Expenditure / Passenger / Km = $\frac{96823.361}{5*33954.12}$ = Rs.0.570 / Passenger / Km

Earning / half Trip = Rs. 55.55

Earning / Month = 55.55*17.88*30=Rs.29797.02

Total Earning during Lifetime of battery = 17.88*55.55*30*12*2.11 = Rs.754460.54

Total number of unit of electricity consumed = $\frac{1888.88}{7.31}$ = 258.39 unit of electricity

Number of km travelled / month = 17.88*30*2.5 = 1341 Km

As per WBSEDCL one unit (KWh) of electricity cost = Rs. 7.31

$CO_2$ emitted / month = 258.39*0.91 = 235.1349 kg of $CO_2$ = 235134.9 g of CO2

$SO_2$ emitted / month = 258.39*6.94 = 1793.22 g of $SO_2$ =1.793 Kg of SO2

NO emitted / month = 258.39*4.22 = 1090.40 g of NO = 1.0904 Kg of NO

$CO_2$ emitted / Passenger / Km = $\frac{235134.9}{5*1341}$ = 35.06 g of $CO_2$ / Passenger / Km

$SO_2$ emitted / Passenger / Km = $\frac{1793.22}{5*1341}$ = 0.267 g of $SO_2$ / Passenger / Km

NO emitted / Passenger / Km = $\frac{1090.40}{5*1341}$ = 0.162 g of NO / Passenger / Km

Electricity cost / day = $\frac{1888.88}{30}$ = Rs. 62.962

Distilled water cost / day = $\frac{130}{7}$ =Rs.18.57

Earning /day = 17.88*55.55 =Rs.993.234

Expenditure / day = 62.962 + 18.57 = Rs.81.532

Net Earning / day = 993.234 – 81.532 = Rs.911.702

Average cost of toto = Rs.155000

Payback period for Battery = $\frac{34733.332}{911.702}$ = 38.097 days

Payback period for toto =$\frac{155000}{911.702}$ = 170.011 days = 5 months and 20.011 days

## 2. <u>Dumdum</u>

Charging cost /month = Rs.1700

Total charging cost in its Lifetime = 1700*12*2.15 = Rs.43860

Cost of Distilled water / week = Rs.130

Total cost of distilled water in its lifetime = 130*52*2.15 = Rs.14534

Number of Passenger /Half trip = 5

Number of half trip/Day = 17.5

Distance of each Half trip = 2.8Km

Life of Battery = 2.15 Years

Number of Km in Lifetime = 17.5*30*2.8*12*2.15 = 37926 Km

Energy cost / Passenger / Km = $\frac{43860}{5*37926}$ = Rs. 0.231 / Passenger / Km

Cost of New Battery = Rs.8630

Total number of Battery = 4

Total cost of Battery = 4*8630 = Rs. 34520

Resale value of Battery = Rs. 2280

Total Expenditure = 43860 + 14534 + 34520 = Rs.92914

Total Expenditure / Passenger / Km = $\frac{92914}{5*37926}$ = Rs.0.489 / Passenger / Km

Earning / half Trip = Rs.58.5

Earning / Month = 58.5*17.5*30=Rs.30712.50

Total Earning during Lifetime of battery = 17.5*58.5*30*12*2.15 = Rs.792382.50

Total number of unit of electricity consumed = $\frac{1700}{7.31}$ = 232.55 unit of electricity

Number of km travelled / month = 17.5*30*2.8 = 1470 Km

$CO_2$ emitted / month = 232.55*0.91 = 211.6205 kg of $CO_2$ = 211620.5 g of CO2

$SO_2$ emitted / month = 232.55*6.94 = 1613.897 g of $SO_2$ =1.613897 Kg of SO2

NO emitted / month = 232.55*4.22 = 981.361 g of NO = 0.981361 Kg of NO

$CO_2$ emitted / Passenger / Km = $\frac{211620.5}{5*1470}$ = 28.79 g of $CO_2$ / Passenger / Km

$SO_2$ emitted / Passenger / Km = $\frac{1613.897}{5*1470}$ = 0.219 g of $SO_2$ / Passenger / Km

NO emitted / Passenger / Km = $\frac{981.361}{5*1470}$ = 0.133 g of NO / Passenger / Km

Electricity cost / day = $\frac{1700}{30}$ = Rs.56.66

Distilled water cost / day = $\frac{130}{7}$ =Rs.18.57

Earning /day = 17.5*58.5 =Rs.1023.75

Expenditure / day = 56.66 + 18.57 = Rs.75.236

Net Earning / day = 1023.75 – 75.236 = Rs.948.51

Average cost of toto = Rs.155000

Payback period for Battery = $\frac{34520}{948.51}$ = 36.39 days

Payback period for toto =$\frac{155000}{948.51}$ = 163.41 days = 5 months and 13.41 days

### 3. <u>Barrackpore</u>

Charging cost /month = Rs. 1590

Total charging cost in its Lifetime = 1590*12*2.1 = Rs.40068

Cost of Distilled water / week = Rs. 130

Total cost of distilled water in its lifetime = 130*52*2.1 = Rs.14196

Number of Passenger /Half trip = 5

Number of half trip/Day = 17.6

Distance of each Half trip = 2.9 Km

Life of Battery = 2.1 Years

Number of Km in Lifetime = 17.6*30*2.9*12*2.1 = 38586.24 Km

Energy cost / Passenger / Km = $\frac{40068}{5*38586.24}$ = Rs. 0.207 / Passenger / Km

Cost of New Battery = Rs.8365

Total number of Battery = 4

Total cost of Battery = 4*7670 = Rs.33460

Resale value of Battery = Rs. 2270

Total Expenditure = 40068 + 14196 + 33460 = Rs.87724

Total Expenditure / Passenger / Km = $\frac{87724}{5*44226}$ = Rs.0.396 / Passenger / Km

Earning / half Trip = Rs.57.5

Earning / Month = 57.5*17.6*30=Rs.30360

Total Earning during Lifetime of battery = 17.6*57.5*30*12*2.1 = Rs.765072

Total number of unit of electricity consumed = $\frac{1590}{7.31}$ = 217.51 unit of electricity

Number of km travelled / month = 17.6*30*2.9 = 1531.20 Km

$CO_2$ emitted / month = 217.51*0.91 = 197.9341 kg of $CO_2$ = 197934.1 g of CO2

$SO_2$ emitted / month = 217.51*6.94 = 1509.51 g of $SO_2$ =1.50951 Kg of SO2

NO emitted / month = 217.51*4.22 = 917.89 g of NO = 0.91789 Kg of NO

$CO_2$ emitted / Passenger / Km = $\frac{197934.1}{5*1531.2}$ = 25.85 g of $CO_2$ / Passenger / Km

$SO_2$ emitted / Passenger / Km = $\frac{1509.51}{5*1531.2}$ = 0.197 g of $SO_2$ / Passenger / Km

NO emitted / Passenger / Km = $\frac{917.89}{5*1531.2}$ = 0.119 g of NO / Passenger / Km

Electricity cost / day = $\frac{1590}{30}$ = Rs.53

Distilled water cost / day = $\frac{130}{7}$ =Rs.18.57

Earning /day = 17.6*57.5 =Rs.1012

Expenditure / day = 53 + 18.57 = Rs.71.57

Net Earning / day = 1012 – 71.57 = Rs.940.43

Average cost of toto = Rs.155000

Payback period for Battery = $\frac{33460}{940.43}$ = 35.57 days

Payback period for toto = $\frac{155000}{940.43}$ = 164.81 days = 5 months and 14.81 days

**4. New Garia**

Charging cost /month = Rs.1787.50

Total charging cost in its Lifetime = 1787.50*12*2.125 = Rs.45581.25

Cost of Distilled water / week = Rs. 130

Total cost of distilled water in its lifetime = 130*52*2.125 = Rs.14365

Number of Passenger /Half trip = 5

Number of half trip/Day = 17.875

Distance of each Half trip = 2.81Km

Life of Battery = 2.125 Years

Number of Km in Lifetime = 17.875*30*2.81*12*2.125 = 38424.99 Km

Energy cost / Passenger / Km = $\frac{45581.25}{5*38424.99}$ = Rs. 0.237 / Passenger / Km

Cost of New Battery = Rs.8750

Total number of Battery = 4

Total cost of Battery = 4*8750 = Rs.35000

Resale value of Battery = Rs. 2312.5

Total Expenditure = 45581.25 + 14365 + 35000 = Rs.94946.25

Total Expenditure / Passenger / Km = $\frac{94946.25}{5*38424.99}$ = Rs.0.494 / Passenger / Km

Earning / half Trip = Rs.57.50

Earning / Month = 57.50*17.875*30=Rs.30834.375

Total Earning during Lifetime of battery = 17.875*57.50*30*12*2.125 = Rs.786276.56

Total number of unit of electricity consumed = $\frac{1787.50}{7.31}$ = 244.52 unit of electricity

Number of km travelled / month = 17.875*30*2.81 = 1506.86 Km

$CO_2$ emitted / month = 244.52*0.91 = 222.5132 kg of $CO_2$ = 222513.2 g of CO2

$SO_2$ emitted / month = 244.52*6.94 = 1696.96 g of $SO_2$ =1.69696 Kg of SO2

NO emitted / month = 244.52*4.22 = 1031.87 g of NO = 1.03187 Kg of NO

$CO_2$ emitted / Passenger / Km = $\frac{222513.2}{5*1506.86}$ = 29.53 g of $CO_2$ / Passenger / Km

$SO_2$ emitted / Passenger / Km = $\frac{1696.96}{5*1506.86}$ = 0.225 g of $SO_2$ / Passenger / Km

NO emitted / Passenger / Km = $\frac{1031.87}{5*1506.86}$ = 0.136 g of NO / Passenger / Km

Electricity cost / day = $\frac{1787.50}{30}$ = Rs.59.58

Distilled water cost / day = $\frac{130}{7}$ =Rs.18.57

Earning /day = 17.875*57.5 =Rs.1027.81

Expenditure / day = 59.58 + 18.57 = Rs.78.15

Net Earning / day = 1027.81 – 78.15 = Rs.949.66

Average cost of toto = Rs.155000

Payback period for Battery = $\frac{35000}{949.66}$ = 36.85 days

Payback period for toto =$\frac{155000}{949.66}$ = 163.21 days = 5 months and 13.21 days

**5. <u>Newtown</u>**

Charging cost /month = Rs. 1785.71

Total charging cost in its Lifetime = 1785.71*12*2.07 = Rs.44357.036

Cost of Distilled water / week = Rs. 130

Total cost of distilled water in its lifetime = 130*52*2.07 = Rs.13993.20

Number of Passenger /Half trip = 5

Number of half trip/Day = 16.14

Distance of each Half trip = 2.85 Km

Life of Battery = 2.07 Years

Number of Km in Lifetime = 16.14*30*2.85*12*2.07 = 34278.45 Km

Energy cost / Passenger / Km = $\frac{44357.036}{5*34278.45}$ = Rs. 0.258 /Passenger /Km

Cost of New Battery = Rs.8507.14

Total number of Battery = 4

Total cost of Battery = 4*8507.14 = Rs.34028.56

Resale value of Battery = Rs.2314.28

Total Expenditure = 44357.036 + 13993.20 + 34028.56 = Rs.92378.816

Total Expenditure / Passenger / Km = $\frac{92378.816}{5*34278.45}$ = Rs.0.538 / Passenger /Km

Earning / half Trip = Rs.57.14

Earning / Month = 57.15*16.14*30=Rs.27672.03

Total Earning during Lifetime of battery = 16.14*57.15*30*12*2.07 = Rs.687373.22

Total number of unit of electricity consumed = $\frac{1785.71}{7.31}$ = 244.28 unit of electricity

Number of km travelled / month = 16.14*30*2.85 = 1379.97 Km

$CO_2$ emitted / month = 244.28*0.91 = 222.2948 kg of $CO_2$ = 222294.8 g of CO2

$SO_2$ emitted / month = 244.28*6.94 = 1695.30 g of $SO_2$ =1.6953 Kg of SO2

NO emitted / month = 244.28*4.22 = 1030.86 g of NO = 1.03086 Kg of NO

$CO_2$ emitted / Passenger / Km = $\frac{222294.8}{5*1379.97}$ = 32.21 g of $CO_2$ / Passenger / Km

$SO_2$ emitted / Passenger / Km = $\frac{1695.30}{5*1379.97}$ = 0.245 g of $SO_2$ / Passenger / Km

NO emitted / Passenger / Km = $\frac{1030.86}{5*1379.97}$ = 0.149 g of NO / Passenger / Km

Electricity cost / day = $\frac{1785.71}{30}$ = Rs.59.52

Distilled water cost / day = $\frac{130}{7}$ =Rs.18.57

Earning /day = 16.14*57.14 =Rs.922.239

Expenditure / day = 59.52 + 18.57 = Rs.78.09

Net Earning / day = 922.239 – 78.09 = Rs.844.14

Average cost of toto = Rs.155000

Payback period for Battery = $\frac{34028.56}{844.14}$ = 40.29 days

Payback period for toto =$\frac{155000}{844.14}$ = 183.61 days = 6 months and 3.61 days

### 6. **Dhulagarh**

Charging cost /month = Rs.1616.16

Total charging cost in its Lifetime = 1616.16*12*2.08 = Rs.40339.35

Cost of Distilled water / week = Rs.130

Total cost of distilled water in its lifetime = 130*52*2.08 = Rs.14060.80

Number of Passenger /Half trip = 5

Number of half trip/Day = 16.33

Distance of each Half trip = 2.5 Km

Life of Battery = 2.08 Years

Number of Km in Lifetime = 16.33*30*2.5*12*2.08 = 30569.76 Km

Energy cost / Passenger / Km = $\frac{40339.35}{5*30569.76}$ = Rs. 0.263 / Passenger / Km

Cost of New Battery = Rs.8233.33

Total number of Battery = 4

Total cost of Battery = 4*8233.33 = Rs.32933.32

Resale value of Battery = Rs.2250

Total Expenditure = 40339.35 + 14060.80 + 32933.32 = Rs.87333.47

Total Expenditure / Passenger / Km $=\frac{87333.47}{5*30569.76}$ = Rs.0.571 / Passenger / Km

Earning / half Trip = Rs.55.83

Earning / Month = 55.83*16.33*30=Rs.27351.11

Total Earning during Lifetime of battery = 16.33*55.83*30*12*2.08 = Rs.682683.88

Total number of unit of electricity consumed = $\frac{1616.66}{7.31}$ = 221.15 unit of electricity

Number of km travelled / month = 16.33*30*2.5 = 1224.75 Km

$CO_2$ emitted / month = 221.15*0.91 = 201.2465 kg of $CO_2$ = 201246.5 g of CO2

$SO_2$ emitted / month = 221.15*6.94 = 1534.78 g of $SO_2$ =1.53478 Kg of SO2

NO emitted / month = 221.15*4.22 = 933.253 g of NO = 0.933253 Kg of NO

$CO_2$ emitted / Passenger / Km = $\frac{201246.5}{5*1224.75}$ = 32.86 g of $CO_2$ / Passenger / Km

$SO_2$ emitted / Passenger / Km = $\frac{1534.78}{5*1224.75}$ = 0.250 g of $SO_2$ / Passenger / Km

NO emitted / Passenger / Km = $\frac{933.253}{5*1224.75}$ = 0.152 g of NO / Passenger / Km

Electricity cost / day = $\frac{1616.66}{30}$ = Rs.53.88

Distilled water cost / day = $\frac{130}{7}$ =Rs.18.57

Earning /day = 16.33*55.83 =Rs.911.709

Expenditure / day = 53.88 + 18.57 = Rs.72.45

Net Earning / day = 911.709 – 72.45 = Rs.839.259

Average cost of toto = Rs.155000

Payback period for Battery = $\frac{32933.32}{839.259}$ = 39.24 days

Payback period for toto $=\frac{155000}{839.259}$ = 184.68 days = 6 months and 4.68 days

## For Lithium-ion Battery

### 1. Mukundapur

Charging cost /month = Rs.744.44

Total charging cost in its Lifetime = 744.44*12*5.44 = Rs.48597.04

Number of Passenger /Half trip = 5

Number of half trip/Day = 23

Distance of each Half trip = 2.5 Km

Life of Battery = 5.44 Years

Number of Km in Lifetime = 23*30*2.5*12*5.44 = 112608 Km

Energy cost / Passenger / Km = $\frac{48597.04}{5*112608}$ = Rs. 0.086 / Passenger / Km

Cost of New Battery = Rs.86000

Resale value of Battery = Rs.2416.16

Total Expenditure = 48597.04 + 86000 = Rs.134597.04

Total Expenditure / Passenger / Km = $\frac{134597.04}{5*112608}$ = Rs.0.239 / Passenger / Km

Earning / half Trip = Rs. 58.88

Earning / Month = 58.88*23*30=Rs.40627.20

Total Earning during Lifetime of battery = 23*58.88*30*12*5.44 = Rs.2652143.616

Total number of unit of electricity consumed = $\frac{744.44}{7.31}$ = 101.83 unit of electricity

Number of km travelled / month = 23*30*2.5 = 1725 Km

$CO_2$ emitted / month = 101.83*0.91 = 92.665 kg of $CO_2$ = 92665 g of CO2

$SO_2$ emitted / month = 101.83*6.94 = 706.7002 g of $SO_2$ =0.7067 Kg of SO2

NO emitted / month = 101.83*4.22 = 429.722 g of NO = 0.429722 Kg of NO

$CO_2$ emitted / Passenger / Km = $\frac{92665}{5*1725}$ = 10.743 g of $CO_2$ / Passenger / Km

$SO_2$ emitted / Passenger / Km = $\frac{706.7002}{5*1725}$ = 0.0819 g of $SO_2$ / Passenger / Km

NO emitted / Passenger / Km = $\frac{429.722}{5*1725}$ = 0.0498 g of NO / Passenger / Km

Electricity cost / day = $\frac{744.14}{30}$ = Rs.24.80

Earning /day = 23*58.88 =Rs.1354.24

Net Earning / day = 1354.24 – 24.80 = Rs.1329.44

Average cost of toto = Rs.280000

Payback period for Battery = $\frac{86000}{1329.44}$ = 64.68 days

Payback period for toto =$\frac{280000}{1329.44}$ = 210.614 days = 7 months and 0.614 days

2. **Dumdum**

Charging cost /month = Rs.725

Total charging cost in its Lifetime = 725*12*5.33 = Rs.46371

Number of Passenger /Half trip = 5

Number of half trip/Day = 22.5

Distance of each Half trip = 2.58 Km

Life of Battery = 5.33 Years

Number of Km in Lifetime = 22.5*30*2.58*12*5.33 = 111386.34 Km

Energy cost / Passenger / Km = $\frac{46371}{5*111386.34}$ = Rs. 0.083 / Passenger / Km

Cost of New Battery = Rs.85500

Total number of Battery = 1

Resale value of Battery = Rs.2291.66

Total Expenditure = 46371 + 85500 = Rs.131871

Total Expenditure / Passenger / Km =$\frac{131871}{5*111386.34}$ = Rs.0.236 / Passenger / Km

Earning / half Trip = Rs.58.33

Earning / Month = 58.33*22.5*30=Rs.39372.75

Total Earning during Lifetime of battery = 22.5*58.88*30*12*5.33 = Rs.2518281.09

Total number of unit of electricity consumed = $\frac{725}{7.31}$ = 99.17 unit of electricity

Number of km travelled / month = 22.5*30*2.58 = 1741.50 Km

$CO_2$ emitted / month = 99.17*0.91 = 90.2447 kg of $CO_2$ = 90244.7 g of CO2

$SO_2$ emitted / month = 99.17*6.94 = 688.239 g of $SO_2$ =0.688239 Kg of SO2

NO emitted / month = 99.17*4.22 = 418.497 g of NO = 0.418497 Kg of NO

$CO_2$ emitted / Passenger / Km = $\frac{90244.7}{5*1741.5}$ = 10.364 g of $CO_2$ / Passenger / Km

$SO_2$ emitted / Passenger / Km = $\frac{688.239}{5*1741.5}$ = 0.0790 g of $SO_2$ / Passenger / Km

NO emitted / Passenger / Km = $\frac{418.497}{5*1741.5}$ = 0.048 g of NO / Passenger / Km

Electricity cost / day = $\frac{725}{30}$ = Rs.24.16

Earning /day = 22.5*58.33 =Rs.1312.425

Net Earning / day = 1312.425 – 24.16 = Rs.1288.26

Average cost of toto = Rs.280000

Payback period for Battery = $\frac{85500}{1288.26}$ = 66.36 days

Payback period for toto =$\frac{280000}{1288.26}$ = 217.34 days = 7 months and 7.34 days

### 3. <u>Barrackpore</u>

Charging cost /month = Rs. 725

Total charging cost in its Lifetime = 725*12*5.5 = Rs.47850

Number of Passenger /Half trip = 5

Number of half trip/Day = 23.33

Distance of each Half trip = 2.50 Km

Life of Battery = 5.5 Years

Number of Km in Lifetime = 23.33*30*2.5*12*5.5 = 115483.50 Km

| |
|---|
| Energy cost / Passenger / Km = $\frac{47850}{5*115483.5}$ = Rs. 0.082 / Passenger / Km |

Cost of New Battery = Rs.84500

Total number of Battery = 1

Resale value of Battery = Rs.2333.34

Total Expenditure = 47850 + 84500 = Rs.132350

| |
|---|
| Total Expenditure / Passenger / Km = $\frac{132350}{5*115483.50}$ = Rs.0.229 / Passenger / Km |

Earning / half Trip = Rs.57.50

Earning / Month = 57.50*23.33*30=Rs.40244.25

| |
|---|
| Total Earning during Lifetime of battery = 23.33*57.50*30*12*5.5 = Rs.2656120.50 |

Total number of unit of electricity consumed = $\frac{725}{7.31}$ = 99.17 unit of electricity

Number of km travelled / month = 23.33*30*2.50 = 1749.75 Km

$CO_2$ emitted / month = 99.17*0.91 = 90.2447 kg of $CO_2$ = 90244.7 g of CO2

$SO_2$ emitted / month = 99.17*6.94 = 688.239 g of $SO_2$ =0.688239 Kg of SO2

NO emitted / month = 99.17*4.22 = 418.497 g of NO = 0.418497 Kg of NO

| |
|---|
| $CO_2$ emitted / Passenger / Km = $\frac{90244.7}{5*1749.75}$ = 10.315 g of $CO_2$ / Passenger / Km |
| $SO_2$ emitted / Passenger / Km = $\frac{688.239}{5*1749.75}$ = 0.0786 g of $SO_2$ / Passenger / Km |
| NO emitted / Passenger / Km = $\frac{418.497}{5*1749.75}$ = 0.0478 g of NO / Passenger / Km |

Electricity cost / day = $\frac{725}{30}$ = Rs.24.16

Earning /day = 23.33*57.5 =Rs.1341.475

Net Earning / day = 1341.475 – 24.16 = Rs.1317.315

Average cost of toto = Rs.280000

Payback period for Battery = $\frac{84500}{1317.315}$ = 64.14 days

Payback period for toto =$\frac{280000}{1317.315}$ = 212.55 days = 7 months and 2.55 days