Barriers of Recycling Batteries in Nepal

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Abstract. With substantial increase in demand of batteries for electric, electronic and vehicular applications, significance of battery recycling technologies is growing in Nepal. Due to novelty and continuous developments in battery technologies, deploying suitable recycling method has to undergo different challenges. This paper analyses number of different types of batteries imported in Nepal, reflects on contemporary battery recycling technologies and categorizes potential barriers associated with their establishment and operation based on review of literatures. The study shows Manganese Dioxide and Lithium-ion batteries are most abundantly used in Nepal. Many of the battery chemistry are not recognized in the official document. Lack of technical for mechanical treatment and uncertainty on appropriateness of chemical treatments due to unclear statistics of types of batteries in the country, establishing viable recycling plant at current stage is challenging. However, due to increased consumption of batteries in different sectors, predominantly increasing in automobile, establishing recycling plant would be an opportunity for the country to extract raw materials for in-house manufacturing of batteries.

1. Introduction

Globally, the total worth of batteries demand is projected to rise 8.1% annually to $156 billion in 2024, majority of which would be consumed by Battery Electric Vehicles (EVs) [1]. The growing market of batteries is an indication of huge amount of digital waste, posing threat to environment and human health [2]. Along with the rise in demand, the price of raw materials, such as lithium, has also increased [3]. About 1000 GWh worth capacity of batteries are estimated to be available for second life, applicable for backup power and stationary energy, by 2030 [4]. After the second life of batteries, they would have to either be disposed or recycled. Since the spent batteries contain concentrated source of metals, possibly higher than that in natural ores, their recovery reduces both economic and environmental burden for manufacturing of new batteries [5]. Nepal has not been aloof from extensive usage of batteries in vehicles and electrical and electronic devices. This paper aims to analyse barriers present in Nepal for installation of battery recycling plants.

2. Method

This paper first analyses types and number of batteries being used for different applications in Nepal through data obtained from Department of Customs under Ministry of Finance of the country. Then, it illustrates battery recycling technologies and categorizes potential barriers associated with their installation and operation through review of literatures. Finally, it analyses barriers in the context of Nepal and recommends probable solution to address those barriers. The research questions for the study conducted in this paper are:

- What is the status of battery usage in Nepal?
- What are the battery recycling technologies present worldwide?
- What are the possible barriers of establishing a battery recycling plant?
- What is the suitable solution to addressing possible barriers of establishing a battery recycling plant in Nepal?

3. National Scenarios of Batteries

Nepal has been importing batteries regularly in the form of battery packs, accumulators, primary cells, and embedded in laptops, mobiles, tablets and electric vehicles as suggested by 'Foreign Trade Statistics' published by Department of Customs [6]. The data from Fiscal Year 2014/15 to 2020/21 shows that Lead-Acid, Nickel-Cadmium, Nickel-Iron, Nickel Metal Hydride and Lithium-ion batteries are being used as vehicle accumulators, and Manganese Dioxide, Mercuric Oxide, Silver Oxide, Lithium and Air-Zinc batteries are being used as primary cells. The batteries used in laptops, mobiles, tablets and EVs are predominantly Lithium-ion batteries. Figure 1 shows the percentage of different types of batteries being imported in Nepal from 2014 to 2021, excluding those embedded in laptops, mobiles, tablets and EVs. Nickel-Cadmium, Nickel-Iron, Nickel Metal Hydride, Mercuric Oxide and Silver Oxide individually contribute to less than 0.1% of total battery import annually. So, they are not

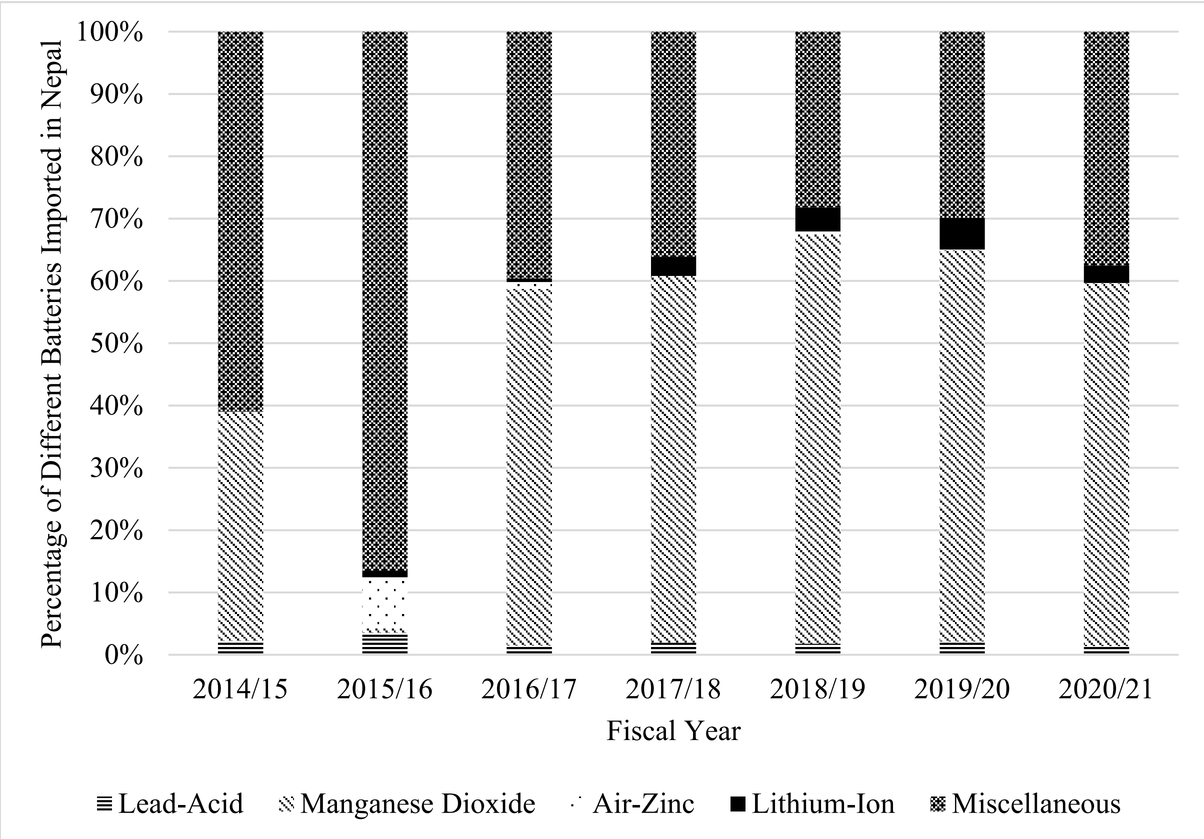

Figure 1. Graph shows percentage of different types of batteries imported in Nepal from Fiscal Year 2014/15 to 2020/21.

shown in the graph. It can be seen that a lot of batteries (under the types 'miscellaneous') are not mentioned with the type of chemistry they have in the official documents provided by the department. Aside from the import of individual batteries, the country has also been importing EVs. The country has a history of operation of trolley bus and battery-operated three-wheelers since 1977 [7] and 1993 [8] respectively in Kathmandu valley. While the former came to a halt in 2008 due to unsupportive policies resulting financial instability, the latter is still in operation [9]. On 2015/16, the country submitted Nationally Determined Contribution (NDC) to United Nations Framework Convention on Climate Change (UNFCCC) with targets to increase share of EVs by up to 20% from 2010 baseline by 2020, decrease transport sector dependency on fossil fuels by 50% by 2050 through mass public transport and energy-efficient and EVs, and developing electric rail network by 2040 to support mass transportation of goods and public commuting [10]. This confirms motivation of the country's stakeholders in promoting EVs in the days to come. Figure 2 shows logarithmic graph with number of different EVs, namely, three-wheelers, two-wheelers and four-wheelers being imported in Nepal from the Fiscal Year 2014/15 to 2021/22. It also shows the number of AC/DC flat chargers being imported since 2018. It can be observed that electric two-wheelers have been imported since 2015 and electric four-wheelers since 2019. A regular trend cannot be observed for the import of EVs, because the import is governed by the ongoing policy practices in the country which is fluctuating. Import of electric chargers, however, shows an increasing trend, suggesting infrastructural development in support of EVs since 2018.

Regardless of trend of import of batteries in the form of individual or embedded systems, Figure 1 and 2 suggests accumulation of spent batteries in the years to come which calls for management of further life of the batteries including second life, recycling and disposal.

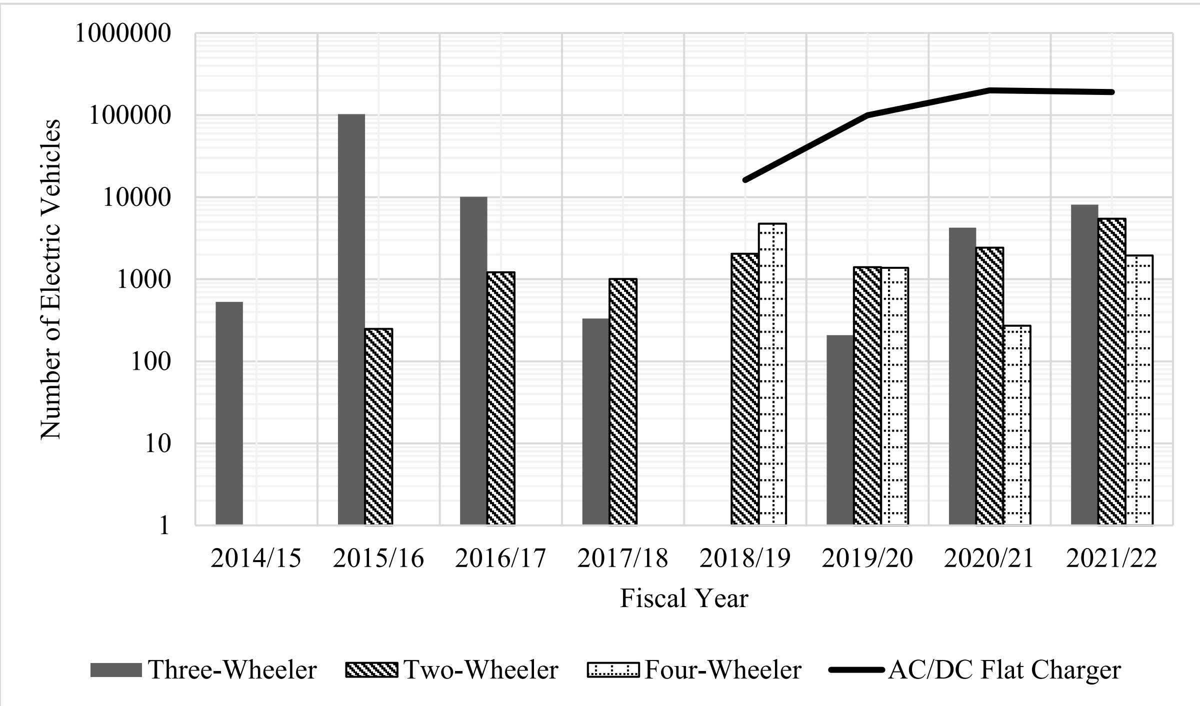

Figure 2. Logarithmic graph shows number of different EVs imported in Nepal from Fiscal Year 2014/15 to 2020/21.

4. Battery Recycling Technologies

Battery being one of the prominent futures for energy demand, proper disposal, recycling, or reuse is vital. The technologies of secondary batteries are evolving with time, but lithium-ion batteries are most widely used [11]. Different recycling plants use different recycling technologies for battery recycling. Predominantly, current recycling technology is based on Lead acid and Lithium-ion batteries that recover valuable material from spent batteries. Battery recycling uses mainly two technologies: Mechanical treatment and Chemical treatment. Before going through the recycling process the State of Health (SOH) is evaluated. If SOH is below 80% then it is recycled, else it is used for second life [12]. Figure 3 shows the block diagram of overall recycling process.

4.1. Mechanical Treatment

Once the batteries are collected, they go through mechanical treatment. The collected batteries are sorted and further dismantled. The sorted batteries are then disassembled to get their components, and are mechanically processed using a hammer mill to break them into parts. Mechanical treatment is used to recycle Lead acid batteries. Lead-acid batteries contains lead, plastic coating known as polypropylene and sulfuric acid. The polypropylene pieces are washed, blown dry and sent to a plastic recycler where the pieces are melted together into an almost-liquid state. The molten plastic is put through an extruder that produces small plastic pellets of a uniform size. The lead grids, lead oxide and other lead parts are cleaned and then melted together using a smelting furnace, During the smelting process fly ash generated from furnace, is a hazardous waste that composed of Copper, Cadmium, Mercury, Lead and Zinc. If these battery wastes are not treated prudently, it poses significant environmental risk. The molten lead is poured into ingot moulds. After a few minutes, the impurities, otherwise known as dross, float to the top of the still-molten lead in the ingot moulds. The dross is scraped away, and the ingots are left to cool. After they are cooled, they are removed from the moulds and sent to battery manufacturers, where they are re-melted and used in the production of new lead plates and other parts for new batteries. Used sulfuric acid can be handled in two ways. The acid can be neutralized and turned into water to release into the public sewage system by meeting clean water standards. Another is to process acid and convert it to sodium sulphate which is used in laundry detergent, glass, and textile manufacturing [13], [14].

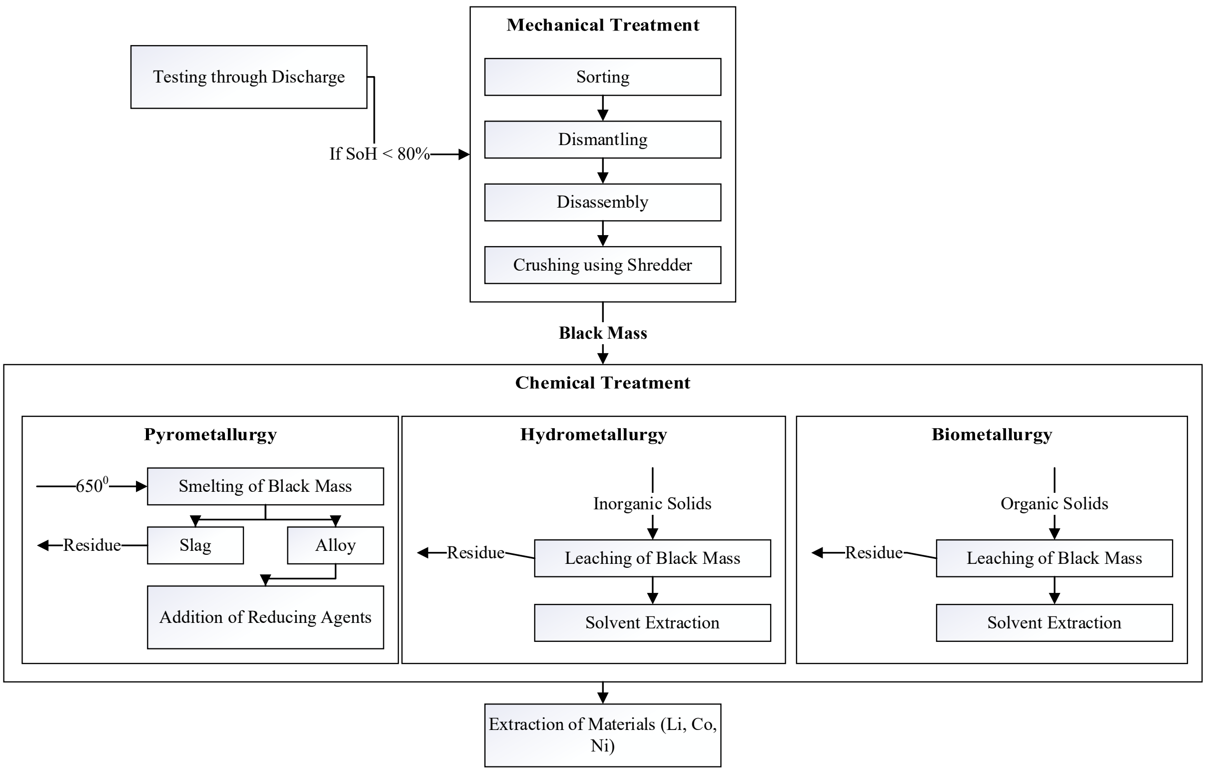

Figure 3. Schematic showing recycling procedures.

4.2. Pyrometallurgy

Pyrometallurgy is a thermal process, which involves separation of material through heating. The recovery of material depends on the metal's sustainability to heat. High temperature can cause burning of metal leading to produce high amounts of slag and gasses. This process has an environmental cost due to high-energy consumption and emission of harmful gasses like CO_2, dioxins and furans into the atmosphere. It has preheating zone, pyrolyzing zone, smelting and reduction zone. Preheating zone has a furnace temperature around 300^0C, which is required to heat the electrolyte. Middle zone is the pyrolyzing zone and the temperature is around 700^0C. Here the exothermic reaction takes place and plastic is removed and remaining material is smelted in the reduction zone where the temperature is around 1200-1450^{0}C. This process recovers nickel, cobalt, copper and iron in the form of alloy and other metals are lost in the form of slag due to high heating [15], [16].

4.3. Hydrometallurgy
Hydrometallurgy uses aqueous solution to recover valuable materials. Pre-treatment of spent batteries like sorting, discharging and disassembling is done before mechanically crushing them. Leaching, purification and separation/precipitation are performed thereafter. Metals are extracted from the raw material, which is further dissolved in the leaching solution. Purification is done by hydroxide precipitation removing copper and aluminium. The hydroxides of copper and aluminium can grow and aggregate to a sufficient size. Subsequently, the solution can be filtered and the residual is supplied to the copper and aluminium production. When the copper and aluminium are precipitated together, it can patent its process for recovery of material from aqueous solution [15], [16], [17], [18].

4.4. Bio metallurgy
Biotechnological processes that involve interactions between microorganisms and metals or metal-bearing minerals are bio metallurgy. Due to their higher efficiency, low cost and lower equipment requirement, bio metallurgical processes are considered to be one of the most promising alternatives to traditional hydrometallurgical processes [19], [20]. Bioleaching is a natural process involving acidophilic bacteria and archaea, which have the ability to either oxidize metal sulphides or to oxidize reduced inorganic sulphur compounds to sulfuric acid, or both. Bioleaching is used today in commercial operations to extract ores of copper, nickel, cobalt, zinc and uranium, whereas bio-oxidation is used in gold processing and coal desulfurization. In bioleaching ferric iron and protons are responsible for carrying out the leaching reactions. Direct bioleaching uses minerals that are easily receptive to oxidation to create a direct enzymatic strike using the microorganisms to separate the metal and the ore. In indirect bioleaching, microorganisms are not in direct contact with minerals during the process. However, leaching agents are created by microbes, which still oxidize the ore [21].

5. Barriers of Recycling Batteries
The barriers of recycling batteries can be divided into four categories, namely, technical, commercialization, policy and awareness. Each of the barriers are described in detail in the following subsections.

5.1. Technical Barriers
Technical barriers include challenges associated with battery design, battery material and chemistry, battery type, material collection and battery removal, each of which are described below:

5.1.1. Battery Design. Lithium-ion batteries typically exists in three main types of enclosures, namely, cylindrical, prismatic and pouch cells. Cylindrical cells exist in many sizes, with the two most common sizes being 18,650 and 26,650. Prismatic cells are rigid and rectangular, and are available in different sizes as well. Pouch cells are available in more variety of shapes and sizes, and often do not have a standard size [22]. These three different types of Lithium-ion battery enclosures are furthermore used to form different modules and packs. Since the packs would have to dismantled before pretreatment, complex enclosures would need more resources to get the battery ready for recycling.

5.1.2. Battery Material and Chemistry. According to a study, in 2015, approximately 350 million personal computers and tablets, few having more than one cell, and about 2 billion cell phones were sold. It was projected that in 2018, over 2.4 billion small consumer cells would be available for recycling [23]. Following the commercialization of Lithium Cobalt Oxide batteries in 1991, the materials used in Lithium-ion cathodes have seen rapid developments. Currently, layered oxides, spinel oxides and polyanion oxides are the three main types of materials used as cathodes [22]. The variety and novelty of the cathode materials make it challenging to sort them and decide appropriate recycling procedure. Further, if the batteries are not manufactured locally, it requires additional resource and skill to decipher the battery chemistry due to privacy issues of the companies and lack of appropriate skill. A study has shown that if the recycling processes are chosen without decoding the battery chemistry, the metal extraction process would be inefficient and unviable [22].

5.1.3. Battery Type. Toyota begun road tests for their prototype EVs with All-Solid-State Battery (ASSB) on June 2020. Volkswagen, Ford and BMW have also been increasing their investments in ASSBs. However, recycling of ASSBs is currently nearly non-existent. In addition, different types of solid-state electrolyte (SSE) chemistries and Lithium metal anodes pose challenges in the recycling processes [24]. The problem is associated with the separation process which must include separation of SSE from other battery components and components with potentially mixed feedstocks. Simultaneously, although Lithium metal provides a high energy density as an anode, it poses a significant safety hazard because of its high reactivity. Thus, there is a need to devise appropriate procedure to recycle ASSBs [25].

5.1.4. Material Collection. No battery can be recycled efficiently until they reach recycling facility. Millions of electronics devices at the end of the life are stored at consumers' as waste for years or sold to scrap dealer [26]. Material collection challenge is of special concern in developing countries because collection of electronic waste is unorganized, and the society lacks awareness regarding benefits associated with recycling. If industry, society and government try collaboratively, large number of waste batteries can be collected for large-scale recycling [27].

5.1.5. Battery Removal from Vehicles. While removing battery from vehicles, a dismantler first removes selected parts from a vehicle for resale, if required, then it depollutes the vehicle by removing the fluids and potentially hazardous materials such as mercury switches and 12V starter batteries. The remainder of the vehicle, known as the hulk, is then sold and shipped to a shredder that recovers the metals [14]. Removing the traction battery from an EV takes skill and time, and puts safety of the person handling the removal on line, adding up to the overall cost of recycling. Proper training, skilled labor and appropriate skills required for the battery removal has to be borne by the recycling plant owner [28].

5.2. Commercialization Barriers

Commercialization barriers of recycling batteries are linked with transportation and logistics, scaling up, economic benefits, battery material requirement, investment in modern technology and fluctuation in raw material prices which are described in the following sections:

5.2.1. Transportation and Logistics. The high energy density of Lithium-ion batteries coupled with presence of flammable organic electrolytes pose the risk of thermal runaway, described as rapid heating and self-ignition due to exothermic chemical reactions [23]. Since Lithium-ion batteries are categorized as Class 9 miscellaneous hazardous materials for transportation purpose, there are clearly defined shipping, packaging, documentation and labeling standards for moving them domestically or internationally. Transportation requirements can include requirements for specific packaging such as thermal insulation, leak-proof inner packaging or drop-tested fiberboard box, provision of labels on the outer packaging, instructions for accompanying documentations, and restrictions on weight or number of batteries or cells [29].

5.2.2. Scaling Up. Scaling up implies upgradation from academic research to initial industrial setup and commercialization. The discrepancies in the laboratory and industry level aspects have to be covered for sustainable initialization of recycling plants [30]. The main challenges that cause low recycling rates are diversity, complexity, lack of regulation and non-standardization of Lithium-ion batteries resulting in difficulties in sorting, disassembly and pretreatment. They reduce profits of recycling plants and make them economically unviable. Besides, there is a range of non-technical challenges, such as logistics concerning collection, transportation and storage of spent Lithium-ion batteries on a large scale [24]. Currently, only 5% of spent Lithium-ion batteries are being collected. These challenges would eventually subside with the standardization of Lithium-ion battery composition available in the market [24].

5.2.3. Economic Benefits. Currently, commercial recycling processes rely on the profits from recovering the valuation cathode materials in Lithium-ion batteries. However, Cobalt, the most valuable element in the cathode, is intentionally being decreased in newly manufactured cathodes. It makes recycling of traditional Lithium-ion batteries economically challenging [30]. Therefore, optimizing or moving on from current recycling technologies to improve profits and maintain economic viability is necessary and urgent. It brings plenty of research opportunities to examine cost reduction and enriches business models such as better disassembling technologies, sorting and separating methods, universal recycling process, design for recycling and standardization of batteries [22]. Recycling efficiency is one of the important factors for the recovery of valuable raw material, which prominently affects the benefit over the cost of battery. The efficiency of battery recycling depends on several factors such as price of raw material, cost of recycling and collection rate, but a feasible infrastructure is of utmost necessity to address environmental and societal costs [30]. Commercial recycling of materials is a consistent effort to improve the infrastructure for sustainable development. Infrastructure development is challenging and significant costs are involved, therefore, prior to its implementation, all the aspects of the infrastructure requirement should be studied. The average recycling output of approximately 50% of the financial value and high costs associated with recycling make the entire recycling process an expensive affair. According to a study done in India, the cost involved in recycling Lithium-ion batteries is around USD 1.1-1.2/kg according to industrial sources[30]. A Lithium battery recycling unit requires high investment in management, resource acquisition and transportation, though the margins are small. Recovering expenses and booking profits takes at least five years [24].

5.2.4. Battery Materials Requirement. Persuading major battery producers to use recycled materials into their production process is difficult. The performance of recycled materials must first be demonstrated to be on par with or better than the virgin materials. The majority of laboratory tests use single-layer pouch cells with minimal electrodes loading, as well as a low active material composition (80 wt%), both of which fall far short of the standard industry criteria (3mAh/cm^2 of electrodes loading and 95 wt% of active materials composition in multi-layer pouch cells). Therefore, normal laboratory research is not close to persuading industrial firms to use recycled materials.

5.2.5. Investment in Modern Technology. By 2030, more than 11 million tons of batteries would reportedly have reached the end of their useful lives worldwide [25]. While it is undeniable that EVs significantly reduce emissions, their expansion without addressing the problems with their batteries will have a negative impact on society and the environment. Benchmark Mineral Intelligence analyzed the investment data in the lithium-ion sector and made it evident that a large percentage of investment is going toward EVs and that end-of-life battery utilization is receiving very little attention. The sustainable development of EVs requires immediate attention [4].

5.2.6. Fluctuation in Raw Material Prices. One of the main economic elements that influences the price of batteries is the cost of raw materials. The cost of batteries is thought to be reduced both economically and environmentally through recycling. While it is true that falling battery raw material prices are favorable for the advancement of EVs, falling raw material prices also present risks for the recycling industry [25]. Lithium and cobalt are two significant elements found in lithium-ion batteries, and research is being conducted across the industry to effectively recover the materials. When lithium's price was USD 25,000 per ton in 2017, it was regarded as white gold. The price decreased by around 60% in 2019 to USD 10,000 per ton [25]. The sustainability of the recycling industry is directly impacted by significant fluctuations in the cost of virgin raw materials. When compared to virgin metal, battery makers might not find secondary or recycled raw materials to be as affordable, which could put recyclers out of business.

5.3. Policy Barriers

No known regulation provides specific guidelines for removing, discharging, disassembling, and storing of used batteries. Few nations, including Japan, Australia, Canada, and the European Union, have made battery recycling mandatory or encouraged voluntary involvement. The recent regulation on the recycling and reuse of traction batteries of New Energy Vehicles in China appears to be a unique first step towards this direction. The country mandates strict guidelines across the entire battery lifecycle, including design, manufacture, sale, maintenance, collection and transport, and finally, reuse and recycle. The health risks associated with collecting, storing, and transporting waste lithium batteries may be a concern. The residual energy can be emitted rapidly and may result in free if the disposed battery is short-circuited [24].

India has prepared policies in support of electric mobility as a contribution to reducing the effects of climate change and controlling the negative impact of battery wastes on climate change, but these policies are ineffective without also establishing policies for used batteries at the end of their useful lives. In order to protect this, the Indian government proposed a recycling strategy for lithium-ion batteries in October 2019. The policy, which is still in the development stage, holds manufacturers accountable for collecting used batteries in accordance with EPR standards [18].

Workplace environmental, health, and safety standards may be required for U.S. No federal policy exists in the U.S. to promote the recycling of Lithium-ion batteries. Older battery technologies are regulated at the federal level under the Mercury-Containing and Rechargeable Battery Management Act [Battery Act] of 1996. Lithium-ion batteries are not toxic or hazardous under the United States Environmental Protection Agency (USEPA) Universal Waste Rule and thus are not covered under the Battery Act, even though they are classified as Class 9 substances by the Department of Transportation because of their fire hazard [23].

The collecting and recycling of used Lithium-ion batteries is mandated by the EU on behalf of product makers. It is hoped that they will include battery end-of-life planning and perhaps include design for recycling in their manufacturing plans. For vehicles weighing less than 3500 kg, the European Union ELV, 2000/53/EC mandates that 85% of them be recycled and reused [19]. The battery directive 2006/66/EG offers instructions for recycling different batteries. The formula for calculating the recycling rate is laid out in EU Commission Regulation 493/2012. The manufacturer of batteries is also responsible for battery recycling and collecting under the battery directive, and they must take the following actions: gathering 95% of the batteries on the market that they made. 50% of the collected battery weight should be recycled [23]. Though the countries have been working towards preparing legal jurisdiction for battery recycling, there are still issues that needs to be addressed in local and global level.

5.4. Awareness Related Barriers

Social barriers are associated with awareness issues, and can be further divided into the following sections:

5.4.1. Social Awareness. Social awareness is critical to advocate reusing and recycling of battery metals that has excellent financial potential [25]. A study done in India has shown that government arrangements alone may not yield intended benefits, both purchaser and manufacturers should actively promote battery recycling. Although, battery recyclers are striving even in the Business to Business (B2B) market, Business to Client (B2C) provides more opportunities for the upcoming years [21]. Eastern Metropolitan Provincial Board of Perth conducted battery reusing program where 55% of school participated [25]. After gathering of adequate amount of batteries from the schools, they are shipped off to New South Ridges for arranging and handling.

5.4.2. Greenhouse Gas (GHG) Emission due to Recycling. Decrease in GHG production is significant objective of Paris Arrangement and recycling contributes to it through energy saving expected at essential stages like mining, transportation, and assembling of unrefined components of batteries. A study has juxtaposed impact of recycling on the different raw material of Lithium-ion batteries with that of the virgin metal [31]. The ozone depleting gases production was decreased by 60-75% from pyrometallurgical process. The general cycle of hydrometallurgy diminishes the ozone depleting substance, and cobalt and nickel recovery does not have significant effect on the ozone [28]. Prior knowledge on environmental aspect of recycling technologies are important before their installation.

6. Discussion and Conclusion

Battery recycling technologies are emerging as a major concern in the contemporary world due to the fact that the demand for battery-dependent technologies is increasing. This paper explores battery market trend in Nepal using statistics provided by Department of Customs, Ministry of Finance, battery recycling technologies and barriers for installation of those technologies. According to the data, Manganese Dioxide is the most common battery chemistry found in the country in the form of primary cell. Rise in number of EVs and charging stations suggests that the Lithium-ion batteries would also be extensively available for second life, recycle or disposal. A large quantity of batteries imported in the country are not categorized based on their chemistries, which makes it difficult for identification while collecting from diverse end-users for further treatment. The recycling process has to undergo SoH test, mechanical treatment, chemical treatment and metal extraction. Deciding proper technology for installation and ensuring viability in the long run requires consideration of barriers beforehand. According to the literatures, the barriers can be classified as technical, commercialization, policy and awareness related. Due to import of large variety of batteries with incomplete identification of chemistries, it is challenging to decide proper recycling technology to make sure the extraction process is efficient. Inefficiency would cause the investment to be economically unfeasible in the long run demotivating the stakeholders to establish recycling plants. Also, lack of skills to dismantle the batteries would add on to the resources required for initiation of recycling plants. Comparatively, pyrometallurgy is resource-intensive, so hydrometallurgy and bio metallurgy could be economical in case of Nepal. Further, absence of policies regarding battery recycling causes dilemma among the stakeholders for long-term investment in the domain. On a bright side, overcoming these barriers could turn out to be opportunity for the country to gather raw materials from spent batteries to manufacture new ones within the country. Further research is required to choose best suitable battery recycling technology for the country.

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