Understanding How Sustainability Issues Manifest in Rechargeable Battery Supply Chains in EV Battery Manufacturers in China, Korea, & Japan

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Executive Summary

This paper analyzes the current state of sustainability in the supply chains of Asia's leading electric vehicle (EV) battery manufacturers. Specifically, we focus on China, Korea & Japan's top EV battery companies, which are CATL, LG, and Panasonic, respectively. We start by reviewing the current state of the technology, mapping the supply chain and then reviewing the demand forecasting for this industry. Next, we assess the major sustainability issues in their supply chains, covering both social and environmental concerns. In light of these issues, we recommend some sustainability strategies, including product innovation solutions and recycling as well as reuse initiatives. Finally, we identify opportunities for supply chain analytics in design and operations of battery supply chains and recharging infrastructure. Overall, we found these companies are under significant pressure to increase the sustainability of their operations and will need to invest in sustainability strategies to meet the skyrocketing demands of the electric automotive industry. At the same time, these companies will need to consider resource constraints of raw mineral inputs and begin to invest in circular approaches and product innovation that mitigate these risks while continuing to reduce environmental footprint.

Understanding state of the art in the rechargeable battery technology

Electric-vehicle batteries are used to power hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), micro-hybrid electric vehicles (μ-HEVs), and battery-powered electric vehicles (BEVs).[i] These batteries are typically lithium-ion batteries which are deep-cycle batteries, meaning they are regularly discharged using most of their energy capacity. Lithium-ion batteries offer high energy density and can be recharged daily at any state of charge.[ii] They are less expensive and provide a range of 200-300 miles. The batteries can be charged at Level 1, Level 2, or Level 3 charging stations. Level 1 is the standard household outlet, Level 2 is a public charging station converting AC power (alternate current) to DC power (direct current), and Level 3 is a public charging station known as DC Fast charging, which bypasses the AC current and directly charging the battery at a fast rate. [iii]

Korea - LG Energy Solution Ltd.

LG has the most productive experience among lithium-ion EV manufacturers. They released the world's first Hybrid Electric Vehicle (HEV) lithium-ion battery in 2009. Lithium-ion battery cells use the transfer of lithium ions to complete to store and maintain a charge. To store a charge, lithium ions are released from the positive anode electrode (which contains the lithium in liquid form), diffuse through the separator, and then enter the negative cathode electrode.[iv] While in use, the lithium-ions will be released from the negative anode electrode and will diffuse back through the separator into the positive cathode electrode. There are four major parts to a lithium-ion battery cell: cathode, anode, a separator between the cathode and anode with micropores for lithium ions to get through, and the electrolyte liquid to transfer the ions. The battery cells containing the lithium ions are connected via modules, in a series or parallel, forming a circuit. LG has been able to manufacture lithium-ion batteries that match the range of internal combustion engines by improving durability and heat-resistance through the nano-ceramic coating.[v]

NCM batteries now take up 69% of the lithium-ion battery market. NCM stands for Lithium Nickel Manganese Cobalt Oxide. These batteries offer higher power and density due to the higher lithium diffusion rate. The greater diffusion rate of lithium ions is due to the ions being able to move in two directions through the separator versus the previously used lithium-ion batteries made of lithium, iron, and phosphate (LFP battery technology), which only allowed for ions to move in one direction through the separator.

Japan - Panasonic Corp.

Panasonic is the #1 lithium-ion battery supplier of electric vehicles due to its partnership with Tesla, which recently opened its largest lithium-ion battery factory. In early 2021, Panasonic released lithium-ion batteries with less than 5 percent cobalt; a rare, toxic mineral used to make the cathode. They have plans to remove cobalt entirely from their operations which will be challenging to achieve but better environmentally.[vi]

China - Contemporary Amperex Technology Ltd. (CATL)

To take things further, Contemporary Amperex Technology, the third leading EV battery manufacturer behind Panasonic and BYD, started developing a lithium-ion battery containing no nickel or cobalt.[vii] They have previously supplied NCM and LFP batteries to Tesla, Toyota, Honda, Volkswagon, etc. In addition, CATL recently announced their development of a battery that was "good for 1 million miles."[viii]

Another widely used battery in electric vehicles is NiMH batteries. NiMH batteries are Nickel-Metal Hydride batteries where the positive electrode is nickel oxide hydroxide, and the negative electrode is a hydrogen-absorbing alloy. These battery types offer a range of around 120 miles, have high specific energy, and long life but can be challenging due to cost, heat generation, and controlling hydrogen loss.

The future of batteries is the development of solid-state batteries. This is where the liquid electrolyte would be replaced with a solid electrolyte such as ceramics, glass, etc., which would save space in vehicles and increase energy capacity by 2-10 times, increasing electric vehicle range and charging time. Toyota is set to release the first solid-state battery in 2030.[ix]

Mapping Supply Chain for Batteries

Having a robust regional battery supply chain is one of the most critical factors for the automotive sector, not only for strategic purposes but also in order to reduce transportation emissions between supply chain nodes.[x] In this regard, Asia finds itself well-positioned in terms of geography and purchasing power of the most critical cathode battery metals, nickel, cobalt, and lithium.

Nickel

Widely geographically available from North America to Russia to the Far East, Nickel's primary sourcing challenge lies in refinement. Few countries having the refinement capability to process mined nickel, and of those options, China dominates in both capacity and cost-effectiveness. This fact supports Asian EV battery manufacturers with exceptional regional availability.

Cobalt

Cobalt, on the other hand, is highly concentrated in one country – the Democratic Republic of Congo (DRC) -- responsible for around 65% of the global supply.[xi] With few (if any) EV battery makers regional to Africa, Asian EV supply chain players sit at the same regional disadvantage as European or North American EV automakers. Nevertheless, China has aggressively positioned Chinese mining conglomerates within DRC to directly own, access, and source cobalt resources.[xii] Without as much pressure from the public or stakeholders over ESG concerns regarding controversial mining practices in DRC, China has an advantageous hold on the world's main supply of cobalt, with impressive refinery capacity to match.

Lithium

Lithium is abundant throughout South America, Australia, China, and Africa, facing more constraints from economic extraction profitability than from physical availability. While widely available and more significant in non-Asian regions, the vast majority of lithium (79% of global production in 2019) passes through China for value-added refinement and processing, given Asia immediate access to useable lithium products like lithium hydroxide and lithium carbonate.[xiii]

Demand Forecasting for Battery Manufacturers

The penetration of electric vehicles -- overwhelmingly for household/personal transportation -- is expected to propel year-over-year industry growth of electric storage batteries, with China and Japan respectively forecast to grow their EV markets by 20.5% and 11.5% CAGR from 2020 to 2027.[xiv] By 2027, China, Japan, and Korea are expected to carry 55% of the global EV battery production demand, attributed to early government investment in manufacturing and supply chain positioning, rising incomes and increased domestic demand, increasing petroleum prices, advancements in battery longevity and charging facilities, and greater environmental awareness and social change attitudes in Asia.[xv]

While the expected growing rate of demand for EVs, the pace of supply-side scalability has been called into question. EV manufacturers and their suppliers have already been forced to pause production at times due to upstream battery supply chain shortages, mainly over strained cobalt resources.[xvi] Environmental and social issues aside, cobalt is already expensive and in short supply, and reliant battery manufacturers have extremely limited options to source it outside of DRC. If demand for the metal increases as expected, without improvements in supply availability, it could lead to price spikes and jeopardize the trajectory of the green economy.[xvii] Technological advancement could come to the rescue though, if EV battery makers are able to successfully innovate towards using less or no cobalt in future battery constructions.[xviii]

Sustainability Issues in Battery Supply Chains

Social

EV battery supply chains begin with the mining of raw materials, and it is this stage of the supply chain that has the most ethical concerns. EV battery supply chains rely heavily on cobalt but because of its high cost and ethical concerns regarding labor practices in cobalt mines, EV companies have begun to replace the element with other raw materials such as nickel. However, although companies such as Panasonic have released lithium-ion batteries with less than 5% cobalt and have set goals to completely eliminate the mineral from their supply chains, demand for cobalt has risen by 30% since 2016 because of the skyrocketing demand for EV batteries overall.[xixxx]

60% of the world's supply of cobalt is sourced from the Democratic Republic of Congo (DRC), where child labor has been reported in unregulated mines that sell to the informal market. Not only is child labor principally a violation of human rights, these children are also faced with dangerous conditions as the mines are often subject to collapse and workers inhale toxic dust while working the mines, causing lung disease later in life.[xxi] Currently, 20% of the DRC's cobalt is extracted by 'artisanal' or informal miners where tens of thousands of children work.[xxii] In order to eliminate child labor, the mining industry in DRC needs to be fully formalized and regulated. Additionally, buyers must demand suppliers of cobalt fully audit their supply chains for human rights abuses.

The World Bank has developed the Climate-Smart Mining Initiative to help resource-rich developing countries, such as the DRC, benefit economically and developmentally from the global shift towards clean energy.[xxiii] Additionally, EV companies should consider partnering with the Initiative for Responsible Mining Assurance, an independent third-party certification that audits mines ensuring they are environmentally and socially responsible.[xxiv] It is important that EV companies help facilitate development in these mineral rich-countries by partnering with non-governmental agencies such as the World Bank, the United Nations Development Program and third-party auditing services. If this is not achieved, supply chains for essential minerals will likely be disrupted by political upheaval, corruption, violence & conflict as governments in these mineral-rich nations are often fragile. Additionally, consumers demand ethical and environmental standards more than ever and will likely favor manufacturers that achieve this. Thus, it is in the best interest of EV battery manufacturers to ensure their supply chains for mineral inputs are socially and environmentally responsible and facilitate development in their source countries.

Environmental

The mining of "green conflict minerals" (cobalt, nickel, lithium, rare earths, and aluminum) has caused massive environmental harm globally. As demand continues to skyrocket for EV batteries, suppliers and buyers need to develop more environmentally friendly methods of sourcing these raw inputs. Nickel mines in Indonesia are turning the ocean red causing toxic tides, the draining of water bodies for lithium reserves in Latin America has contributed to a scarcity of clean water and 'water wars' in that region, and deep-sea mining has disrupted biodiversity in oceans as companies attempt to tap into underwater reserves of rare earth minerals in countries such as Fiji.[xxv] EV battery manufacturers and the green energy industry as a whole need to work towards addressing the environmental issues in their supply chains to ensure they are not just solving one environmental problem by creating new environmental problems.

Sourcing minerals is not the only aspect of the EV battery supply chain that needs to improve environmentally. Across the supply chain EV companies are shifting to renewable sources of energy and working to reduce their carbon emissions. Panasonic has launched two Zero-CO2 factories in Japan and Belgium as a part of its push towards carbon neutrality by 2050.[xxvi] Similarly, LG has committed to carbon neutrality by 2050.[xxvii] Meanwhile, CATL continues to broker contracts with major European car manufacturers whose future is electric, such as Daimler, by creating CO-2 neutral production battery cells.[xxviii] These EV battery companies will need to continue to green their operations as car manufacturers increasingly demand carbon-neutrality initiatives and overall reductions in their environmental footprint.

LCA – Footprint of Battery Technology

A Life-Cycle Analysis, or LCA, analyzes the entire supply chain of a product from raw materials to manufacturing to its use stage and end of life, including transportation. From a cradle-to-gate perspective, electric vehicles are better for the environment than internal combustion engine vehicles (ICEVs). However, the only section where electric vehicles come out worse than ICEVs is manufacturing due to the significant environmental impact of battery production. Therefore, we will analyze previously recorded LCAs of NMC (Lithium Nickel Manganese Cobalt Oxide) lithium-ion batteries (LIBs) used in electric vehicles (the most commonly used battery for EVs) to take a closer look at why battery production has such a significant impact on the environment. The stages of a battery's life start from the extraction of raw materials, then processing the materials to become battery-grade, manufacturing battery cells and integrating them into modules, and finally assembling battery packs with a case, cooling system, and battery management system.

Two main LCAs were analyzed and compared. The first, titled "Life Cycle Analysis of Lithium-Ion Batteries for Automotive Applications," did a cradle-to-gate analysis of the energy use, GHG emissions, SOx, NOx, PM10 emissions, and water consumption using the functional unit of 1 kWh NMC111 battery.[xxix] It found that the major contributors to environmental impact were from the active cathode material, aluminum, and cell production. The most significant contributor to NMC Lithium-ion battery impact is the NMC powder (NMC111) which accounts for 66.3% of a battery's total PM10 emissions, 63.5% of its SOx emissions, 47.6% of its NOx emissions, 39.1% of its total GHG emissions, 36.4% of the energy use, and 31.7% of the total water consumption. Aluminum followed in second and cell production in third (due to electronic parts). NMC111 powder is the worst part of battery production for the environment because of the reaction to produce $Ni_{1/3}Mn_{1/3}Co_{1/3}(OH)_2$ via co-precipitation, consuming 42.6 MJ of heat/kg. The following co-precipitation is wastewater treatment at the facility, accounting for a heat demand of 45% to remove the ammonia and sodium sulfate. Next, the calcination with Li_2CO_3 produces the cathode powder, consuming 25.2 MJ of electricity/kg. The raw materials for this step account for 50% of the total battery cost, so facilities' priorities are to maximize yield from raw materials instead of improving energy use. To summarize this LCA, the upstream production of materials incurs the most burden. The three areas with the most considerable environmental impact are manufacturing NMC111, aluminum, and cell production.

"Globally Regional Life Cycle Analysis of Automotive Lithium-ion Nickel Manganese Cobalt Batteries" was the second article that explored the production of NMC111 and found that NMC111 produced in China generates 100 kg CO_2e/kWh.[xxx] This article was congruent with the first, stating that the active cathode material, aluminum, and cell assembly are the key contributors to the environmental impacts of lithium-ion batteries. To produce NMC111 powder, refined nickel gets converted into nickel sulfate, the nickel component of NMC111. Nickel is mined from sulfide or laterite ores then goes through beneficiation, primary extraction, and finally to the refining process. Due to the high temperatures required, mining in sulfide ores can form sulfur dioxide leading to acid rain, making it the most energy-intensive process. To meet these energy demands, natural gas (66%), coal (12%), diesel (11%), and electricity (11%) are all used. Following NMC111 production as the top contributor to environmental impact is aluminum. This type of lithium-ion battery is 24% aluminum, found in the thermal management system, the cathode current collector, and the battery's packaging. The reduction of alumina to produce aluminum makes it energy-intensive, reduced with coal-based electricity brings even more CO_2 emissions. Reducing alumina also produces the potent greenhouse gases CF_4 and C_2F_6. China has 54% of aluminum globally. The third is cell assembly: cell stacking, electrode production, electrolyte filling, current collector welding, cell encasement, and cell closure, all-consuming energy. To add on, to prevent water from reacting with the electrolyte salt, this process must take place in a dry room, requiring heating, cooling, and circulation. This cell assembly process consumes 82.4% natural gas and 17.6% electricity.

Sustainability Strategies

The first step towards more sustainable car batteries is improving their performance through innovation. As previously mentioned, reducing the cobalt in electric vehicle batteries will certainly help reduce their environmental impact. Panasonic, for example, is working towards this goal of zero cobalt, and their batteries already contain less than 5%. Increasing the energy density of batteries will also help to increase their longevity. This will enable increased battery capacity, and thus range, and reduce the number of times a battery will need to be charged which will help to prolong the life of the battery. Another promising option is battery swapping. This is the process of exchanging a depleted battery for a fully charged battery at a station instead of plugging in the battery to recharge it. Battery swapping is much faster than regular charging, and much better for the life of the battery. These swapping stations use trickle charging, which slowly refills the battery instead of the supercharging that degrades the battery. Companies such as Nio and Geely in China are already launching battery swapping stations as an alternative to charging.

Making EV batteries more sustainable also means reusing and repurposing existing car batteries. According to a study that complied the results of 50 life cycle assessments, lithium-ion car batteries still provide 70% of their capacity after 15 years of use, and therefore still have plenty of life remaining after they are removed from an electric vehicle[xxxi]. Applications for these batteries include grid storage and renewable energy storage. Several Asian car makers have already begun implanting these strategies. Nissan, for example, is using old car batteries to power automated machines in their factories and has utilized them for power storage in homes and businesses. Toyota has also reportedly installed old EV batteries for energy storage at convenience stores in Japan. Hypothetically, these depleted batteries could also be reused for electric cars. These cars will of course have shorter travel ranges and reduced charging efficiency, but they could certainly be implemented in a budget electric vehicle market.

A crucial aspect of making the EV battery industry more sustainable is battery recycling. Some studies indicate that large-scale battery recycling could reduce life-cycle emissions of EV's if the proper method is used[xx]. Battery recycling can require high temperatures to smelt and separate metals, which may involve the burning of fossil fuels. This is why the results from life cycle-assessments are mixed. However, recycling batteries certainly reduces their environmental impacts as a whole. Mining, extracting, and processing raw materials is a significant portion of a batteries impacts that can be avoided if the batteries materials are reused[xxxii]. Specifically, reusing the cathode components (cobalt and nickel) as well as aluminum have been proven to reduce environmental impacts the most.

When it comes to disposing of the battery, it should never just be thrown in a landfill. Not only is this bad for the environment, but it is a waste of precious materials and rare earth metals, as well as money. Once a battery is past its usable life, it needs to be broken down and the metals need to be recycled. As car battery production scales dramatically over the next decade, it is paramount that this circular approach is adopted.

Opportunities for supply chain analytics in design and operation of battery supply chains

Predictive Analytics

Various technologies can be used in predictive analytics for the design and operation of the battery supply chains. Machine learning, blockchain, and end-to-end loT technology can be jointly utilized to help people do the analysis more effectively.

Wider adoption of blockchain

When using machine learning for data analysis, the accuracy of the data is very important. Blockchain could help improve the data accuracy and transparency. The ambiguity of data often affects the information sharing and opinion judgment of the supply chain. People can look up the information on blockchain at any time, and this information is always the same and secure. The application of blockchain makes the supply chain more transparent, which helps reduce the costs generated by data errors. This technology can not only be used for data management and sharing, but also for battery raw material tracking. The Chinese-owned Swedish electric car producer Volvo implements blockchain technology in tracing its battery raw material cobalt as shown in Exhibit 6.[xxxiii] Not only China, the other main electric car producers, like BMW, General Motors and Renault have also built the blockchain platform MOBI and aimed to use this technology.[xxxiv]

End-to-End loT

End-to-End loT refers to a technology that understands the project from beginning to end and provides a complete solution.[xxxv] Combined with machine learning, this technology can analyze various kinds of problems and provide solutions accordingly, such as the optimal inventory quantity. When analyzing this regression problem, its feature importance could also be calculated, so that people could know which elements have more significant impacts on the target variable. Then GPS sensors could be used to track goods. Sensors used in warehouses can help track inventory, and adjustments could be made accordingly.

Prescriptive Analytics

Real-Time Data

In terms of inventory management and finding the optimal inventory level of EV battery and raw materials, real-time data is essential. Real-time networks can achieve visibility to all sources, stores, warehouses, suppliers, products in transit, and even the ability to redistribute supplies to match demand. This means greater accuracy in deploying inventory and using the most cost-effective inventory source for customer orders.

Integrated Logistics

In terms of transportation, integrated logistics help people find the optimal route. In order to obtain the best efficiency, the company needs to consider the touch points of the supply chain and make choices for different logistics models. With the help of AI, this technology provides transportation forecasting and control over these selection issues in the supply chain to make the most sensible choices.[xxxvi] This could minimize interruptions and increase customer satisfaction.

Opportunities for supply chain analytics in design and operation of battery recharging infrastructure

Predictive Analytics

Artificial Intelligence

When analyzing problems of battery recharging infrastructure, artificial intelligence can greatly improve people's ability to foresee and solve problems. In real life, the corresponding predictive analytics can be designed to automatically identify and repair problems.

The following are two examples of classification problems. The first is to predict battery usage situation, if the battery needs to be changed or not. We can find out which factors have more important impacts on battery usage situation. The second is to predict if the location needs the establishment of charging piles. Also, the feature importance could be found. The factors like population density, economic status of a location might have essential impacts. As shown in Exhibit 7, taking China as an example, the eastern region with the densest population and the best economic development has the highest requirements for charging piles, followed by the central region, and finally the western region.[xxxvii]

Smart contracts

In the charging payment of electric vehicles, people are increasingly considering the use of smart contracts and crypto-currency, and this is becoming an industry trend.[xxxviii] Through this technology, invoices or financial transactions are automatically generated, thereby improving the efficiency and reducing the occurrence of errors.

Prescriptive Analytics

Optimizing charging state

Optimizing parameters for the optimal charging state is always a problem worth analyzing and different advanced machine learning techniques could work together to address it. The parameters include state of charge (SoC) and state of health (SoH), temperature, current and so on.[xxxix] In order to provide a safe charging environment, the blockchain technology framework and the appropriate network security algorithms are proposed when needed.

Optimizing pricing policies

Prescriptive Analytics can help people optimize the pricing strategy of charging based on the cost of the establishment, use and maintenance of charging piles, and changes of electricity prices. Based on protecting the interests of consumers and ensuring the sustainable growth of the business model, people target the most profitable pricing model. Dynamic pricing schemes are dynamic pricing models that people want to dynamically adjust according to different parameters in order to find the best prices. These parameters could be found in Exhibit 8. According to a questionnaire for 3863 Chinese electricity consumers, 67% of people are ready for dynamic energy pricing. Specific pricing measures under dynamic pricing schemes include "Real Time Pricing (RTP), Time of Use (ToU), Critical Peak Pricing (CPP), and Peak Time Rebates

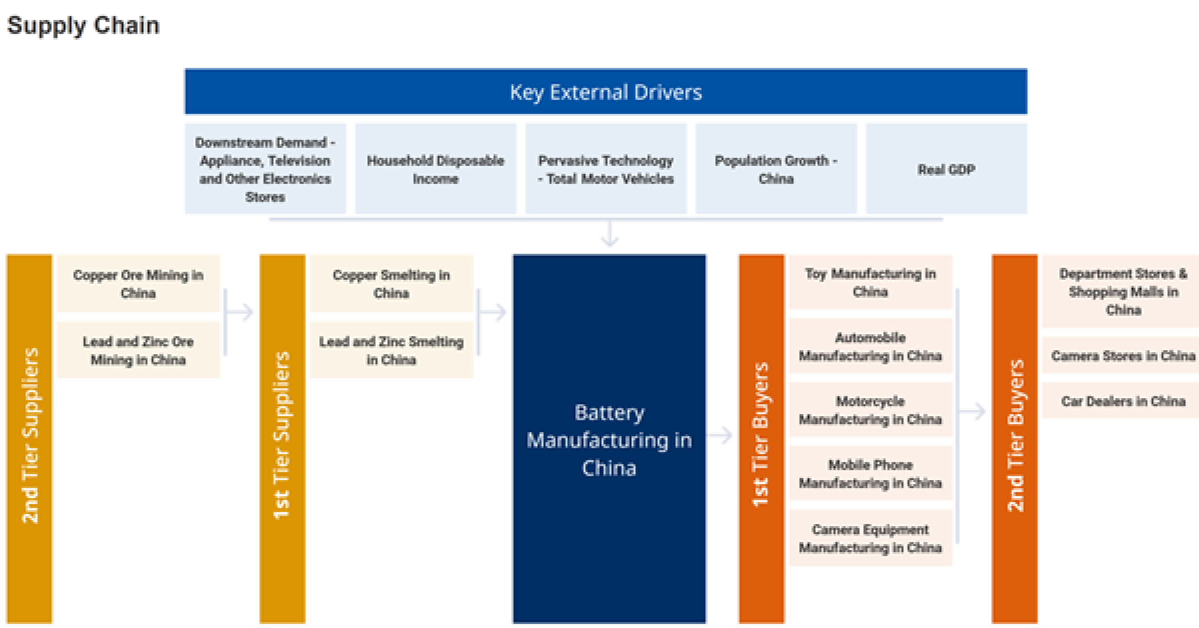
(PTR)".[xl] For example, RTP is adjusting the price at any time based on the electricity demand and supply on the market.

Other Issues of Interest

A subject of interest that we were not able to fully delve into in this analysis is the relationship between EV car manufacturers and the tech industry in regard to their re-usage of EV batteries. When thinking about the circular economy of EV batteries, it is important to remember that many other industries are either already using this technology or are interested in moving towards electric technology and could benefit from end-of-life EV batteries. Specifically, 5G infrastructure, data centers, and energy storage are all examples of industries that could leverage second-hand lithium-ion batteries. According to Greenpeace, "By 2025, the backup power systems for all of China's 5G telecom stations could be supplied by repurposed batteries."[xli] Many governments have made commitments to reduce their overall carbon footprint, such as China's commitment to carbon neutrality by 2060, and investing in the standardization of electric batteries is a strategy to help make these goals a reality. This strategy could integrate a multitude of automotive, energy storage, and tech sectors into a circular economy that would benefit all parties involved and help reduce overall environmental impact. Additionally, it will address the raw mineral constraints of electric battery supply chains that these industries will run into if they only leverage 'new' batteries (it is predicted that from 2021 to 2030, EV battery production will use up 30% of the world's proven cobalt reserves). Cross-industry co-operation will become an important element for the future of sustainability in electric energy and the green economy as a whole.

APPENDIX

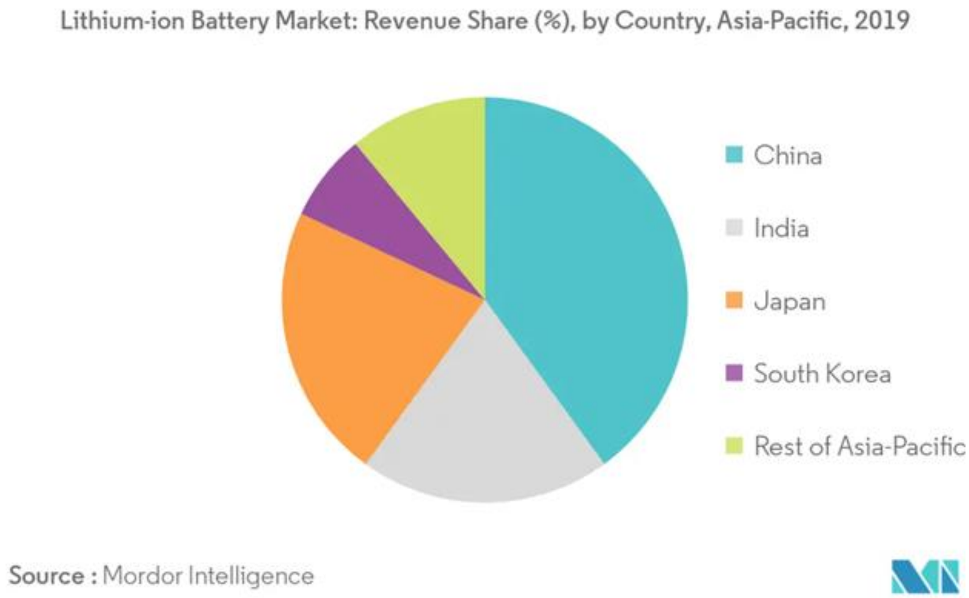
Exhibit 1. Supply Chain Mapping in Asia (China)



Ibis World

Exhibit 2. Li-Ion Market Segmentation by Country

Mordor



Intelligence

Exhibit 3. Battery Costs: Historic and Projected

Bloomberg New Energy Finance

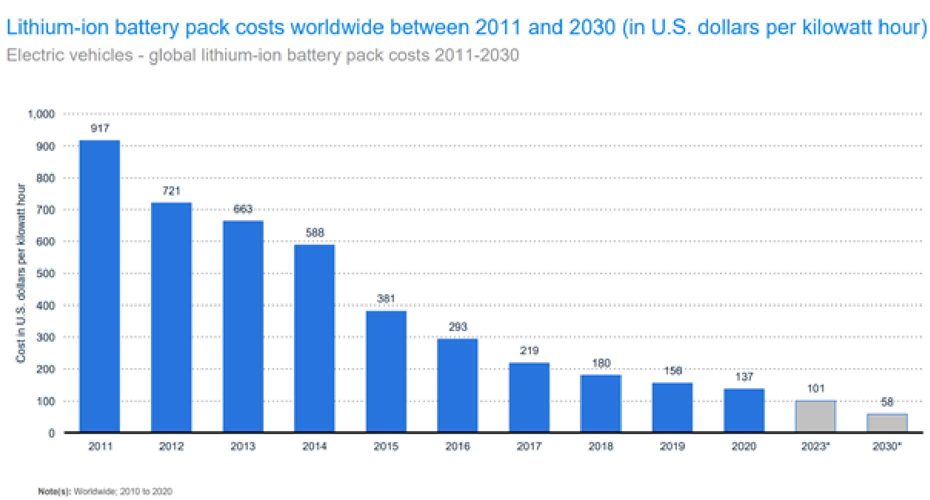
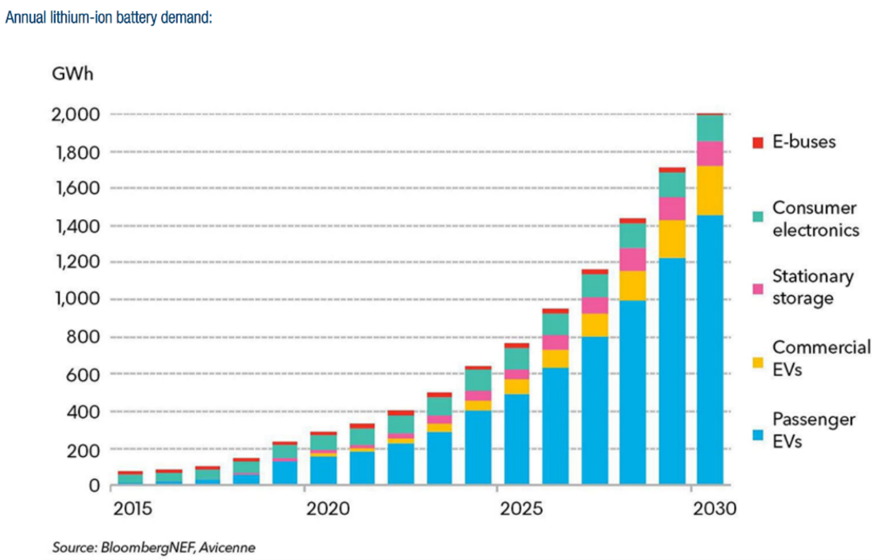
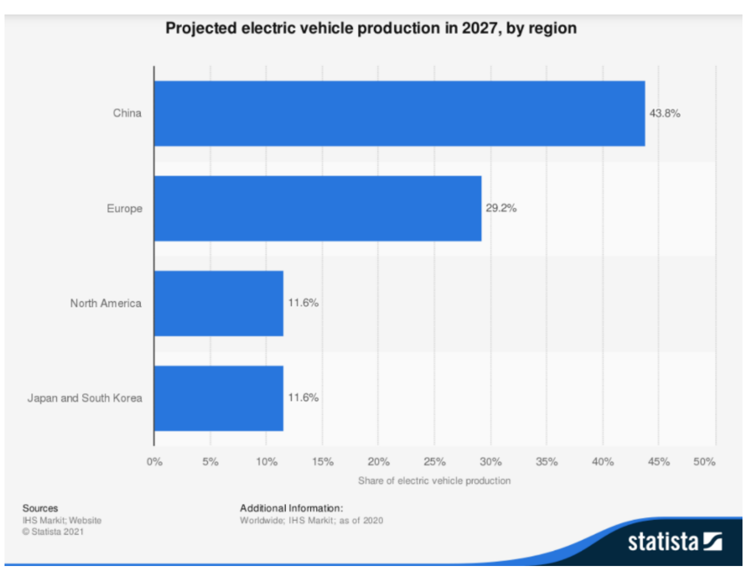


Exhibit 4. Li-Ion Annual Demand

Exhibit 5. EV Vehicle Production 2027

Exhibit 6. Volvo implements blockchain to track Cobalt.[xlii]





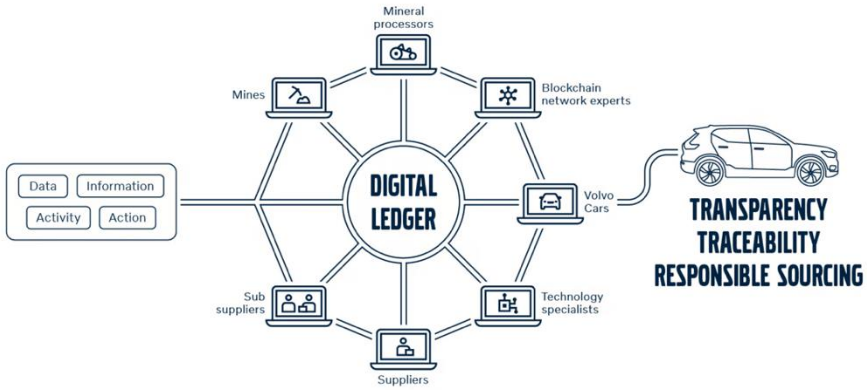


Exhibit 7. Comparison of the number of charging piles in different regions of China[xliii]

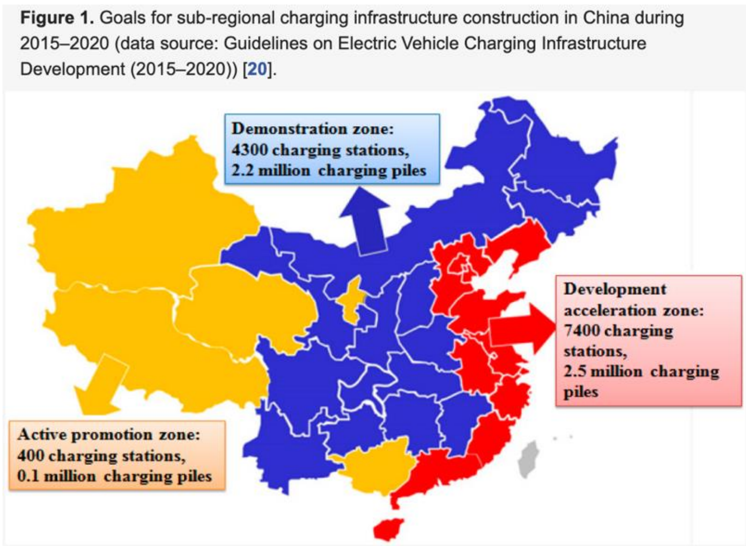
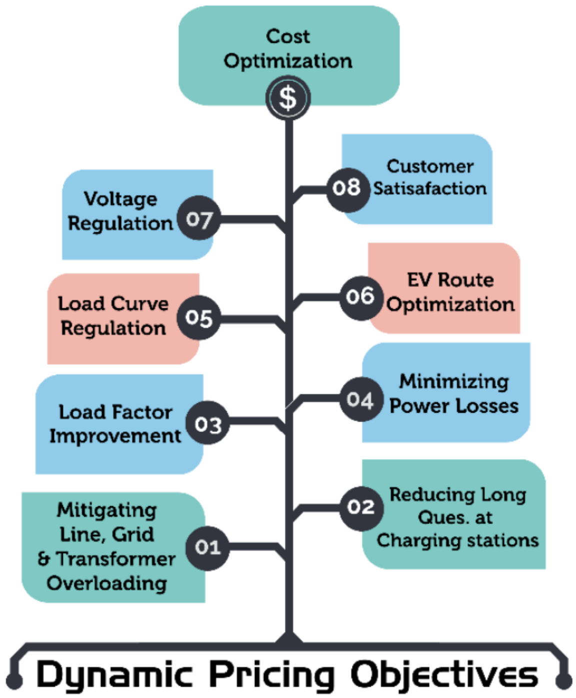


Exhibit 8. Various objectives of dynamic electricity pricing[xliv]



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