HSLU Hochschule Luzern

reEValuate Batteries

Interactive Simulation App for Sustainable Management of Mineral Resources for EV Batteries

Project Report

Module W.MSCIDS_DE_SUA01.H2301: Sustainability Analytics
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1. Abstract

The report addresses the urgent need for sustainable practices in the automotive industry, focusing on the recycling of electric vehicle (EV) batteries. It explores the adequacy of lithium, nickel, and cobalt reserves to meet the growing demand for EVs, which are projected to dominate auto sales by 2050. A predictive model has been created to simulate demand for these minerals, highlighting the need for efficient recycling solutions to support sustainable development goals (SDGs) such as responsible consumption, innovation, and life on land.

Research has been compiled predominantly from the International Energy Agency (IEA) and Statista, examining various statistics and projections on EV batteries. The project emphasizes the importance of strategic planning in resource management to avoid shortages, enhance the resilience of the automotive industry and promote environmental conservation.

An app with adjustable parameters allowing stakeholders to explore different scenarios has been developed using Streamlit. The model showcases the potential shortfall in mineral availability and helps identify major bottlenecks in the supply chain, especially to find the needed recycling rate. The app serves as a call to action for decision-makers to implement regulations that support the transition to a more sustainable and electrified future.

2. Introduction

As climate change continues to be a threat for humanity, there is a need to reduce pollution. The automotive industry is a significant area of focus, particularly with the increasing popularity of electric vehicles (EV). These cars, which are powered by electricity, are considered a significant step towards cleaner driving as they do not emit the usual pollutants associated with traditional cars. According to Wood Mackenzie [4], it is projected that by the year 2050, EVs will account for approximately 80% of all automobile sales.

However, this burgeoning demand raises concerns about the supply chain's ability to keep pace. An electric car requires six times the amount of minerals of a conventional petrol car [3], highlighting a potential mismatch between the world's heightened climate ambitions and the availability of essential minerals. The status of EVs as the ideal solution for a greener future is therefore debatable. While they do not emit pollutants as they drive, the production and recycling of their batteries have some environmental consequences and constraints.

2.1 Goal

This project is focused on gaining a deeper insight into the necessity of recycling batteries for electric vehicles (EVs). Given the finite nature of resources, it's crucial to approach the recycling of EV batteries with strategic importance. Our objective is to analyze and forecast the need of the EV industry for scarce minerals, so that we can showcase the urgency for rapid development of battery recycling solutions. To this end, we develop a predictive model that estimates the demand for three critical battery minerals—Lithium, Nickel, and Cobalt—up to the year 2050. This model will feature adjustable parameters, allowing users to simulate different scenarios and explore their outcomes.

2.2 Stakeholders

The ultimate goal is to develop an application tailored for economical and political decision-makers. It highlights the crucial significance of battery recycling and stresses the need for prompt adoption of solutions and regulatory measures.
The app may also appeal to a wider audience, including unintended stakeholders, as detailed in the accompanying image (Figure 1).

Our strategy with these stakeholders is to gain their interest and secure investment in our project, as we are not offering a commercial product for sale.
In conclusion, our initiative aims to highlight the necessity of managing resources sustainably and to motivate all stakeholders to actively engage in supporting battery recycling efforts.

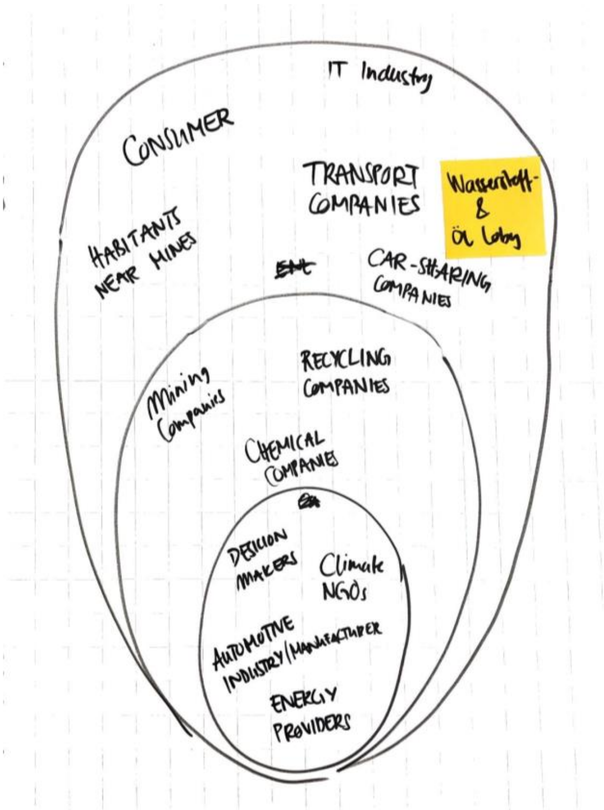

Figure 1: Stakeholder Mapping

2.3 SDGs

This project aligns with and supports the United Nations Sustainable Development Goals ([5] United Nations, 2023), particularly focusing on three key objectives (Figure 2):

SDG 9: Industry, Innovation, and Infrastructure - The project emphasizes the importance of advancing innovative technologies for the efficient production and recycling of batteries, which is essential for the transition to predominantly electric mobility. Achieving this goal requires not only material efficiency but also the development of the necessary infrastructure to support a robust recycling process for EV batteries.

SDG 12: Responsible Consumption and Production - By establishing a closed lifecycle for EV batteries, the project aims to promote responsible production practices. This involves creating systems that allow for the sustainable use and reuse of resources, thus minimizing environmental impact.

SDG 15: Life on Land - By decreasing the demand for mined minerals, the project can contribute to less land disruption and degradation, promoting the conservation of terrestrial ecosystems and biodiversity.

Figure 2: Sustainable Development Goals

3. Approach

Extensive data on EVs and their batteries provide projections on various parameters for the coming years. However, a definitive dataset with conclusive insights into the resources needed for the estimated EV production is not yet available. The recent emergence of EVs results in non-linear trends, making time series analysis less suitable for our purposes. Therefore, we have chosen to develop a system dynamics model for this project. This approach will be used to simulate and analyze the demand for rare minerals critical to EV battery production, effectively accounting for the rapidly evolving dynamics of the EV industry.

3.1 System Dynamic Model Concept

The objective is to develop a straightforward yet insightful model that can assess whether the supply of lithium, nickel, and cobalt will meet the increasing demand for EV batteries in the future. The project team convened a work session to draft and construct a simplified model. After several revisions, we arrived at the subsequent diagram as our outcome.

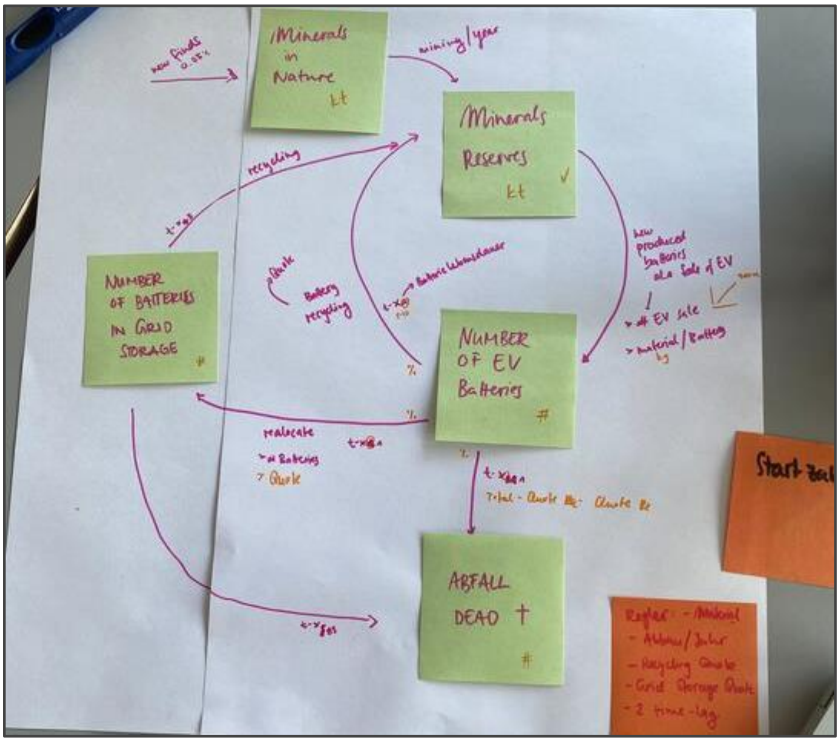

Figure 3: System Boundaries

The team has chosen to define the system boundaries at the supply chain level, excluding economic and environmental factors from our analysis. Our approach starts with minerals in their natural state in the ground and constructs a cycle that includes both the use and reuse of these minerals. Recognizing that not all minerals are recyclable, we've also included a waste stock. Our model includes five different stocks, each quantified in kilotons to represent the volume of the respective minerals (Figure 3). The primary objective is to build the outlined model for each of the key minerals - lithium, nickel and cobalt - that we're looking at. In doing so, we aim to predict potential mismatches between the projected availability of these materials and their expected demand, thereby identifying potential shortages in the supply chain.

To accommodate different scenarios or outcomes, the final application of our model will feature a range of adjustable parameters (more to this in the user interface part). This flexibility will allow users to customize aspects such as recycling, repurpose, and waste rates, offering a tailored analysis based on individual or specific considerations.

3.2 Sources for data

The project team has undertaken extensive research into the various statistics and forecasts relating to the demand for EV batteries and their materials. The primary objective has been to gather predictive data on future EV battery production, encompassing the number of EVs anticipated for manufacture and the volume of materials required for this production. Additionally, we have sought information on the global reserves of essential minerals and the feasibility of their extraction.

In our findings, it became evident that sources offer divergent outlooks based on different scenarios, each reflecting a range of possible futures for battery demand. These scenarios consider a variety of factors, including technological advancements, policy developments, and market trends, which all influence the projected needs for EV batteries.

- Stated policies: This scenario typically reflects the outcomes based on existing policy frameworks and regulations without assuming any further policy changes. It suggests what could happen if the world only follows through with the climate and energy policies that have already been set in place.
- Announced pledges: This scenario takes into account the targets and goals that countries or companies have publicly committed to, even if these pledges have not yet been codified into policy. It provides insight into potential futures if these pledges are fully realized.
- Net zero 2050 scenario: This scenario outlines a pathway for the world to achieve a balance between the amount of greenhouse gases emitted and the amount removed from the atmosphere by 2050. This would be in line with keeping global warming to 1.5°C above pre-industrial levels, as per the Paris Agreement goals.

In building our use case, we predominantly utilized data from the International Energy Agency (IEA) complemented by additional statistics from Statista. A comprehensive breakdown of the sources consulted and the specific estimates selected for our analysis can be found in Chapter Solution of our report.

3.3 User Interface Prototyping

Prior to beginning the programming work, the team made strategic decisions regarding the model's parameters. We determined which parameters would be hardcoded (set in the model), which would be adjustable by users, and which would dynamically change in response to user input. These predefined parameters can be found below (Figure 4). Following these decisions, the team proceeded to develop the user interface using Streamlit. Below is a very first prototype of the app, which helped the team to find meaningful visualizations and parameter settings.

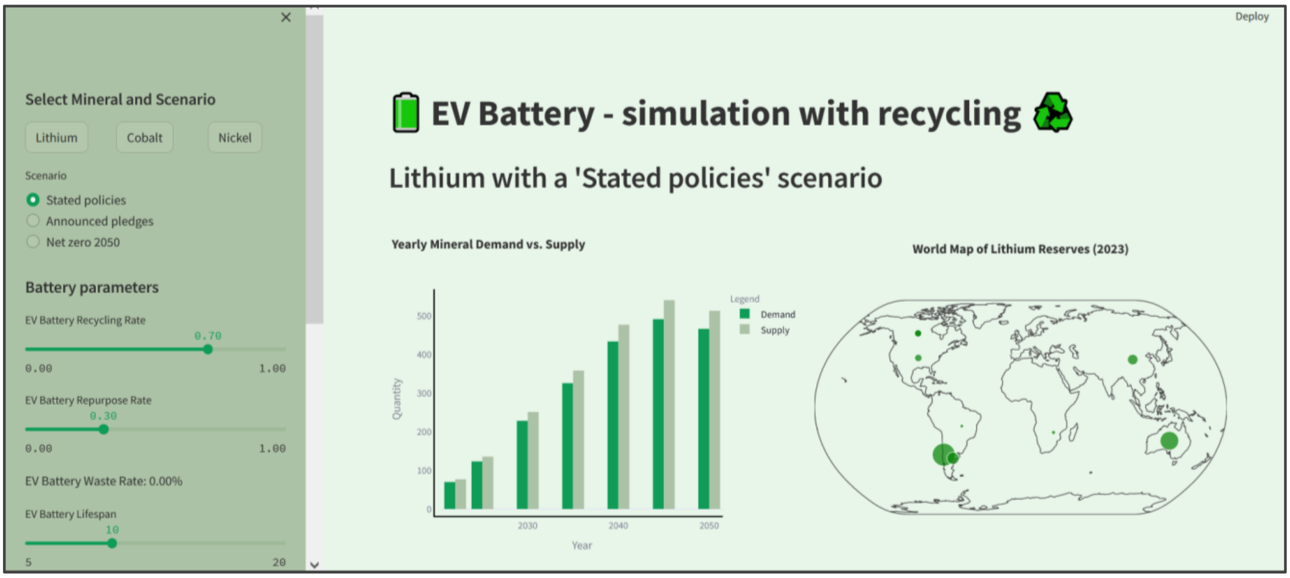

Figure 4: App Prototype

4. Solution

After designing and conceptualizing the solution, we proceeded to program the model and its corresponding interface. In the initial phase, we provided a detailed explanation of the model's logic and underlying data to ensure clarity and understanding.

4.1 Model architecture and data

This section discusses the structure of our system model and the reasoning behind its logic, values, and computations.

The diagram below presents our system dynamics model, where each rectangular shape is a stock, which represents a repository of a mineral in kilotons at different stages within the supply chain system. The connecting lines represent the flows, which illustrate the movement between these stocks, whether through processes such as mining, production, recycling, or disposal.

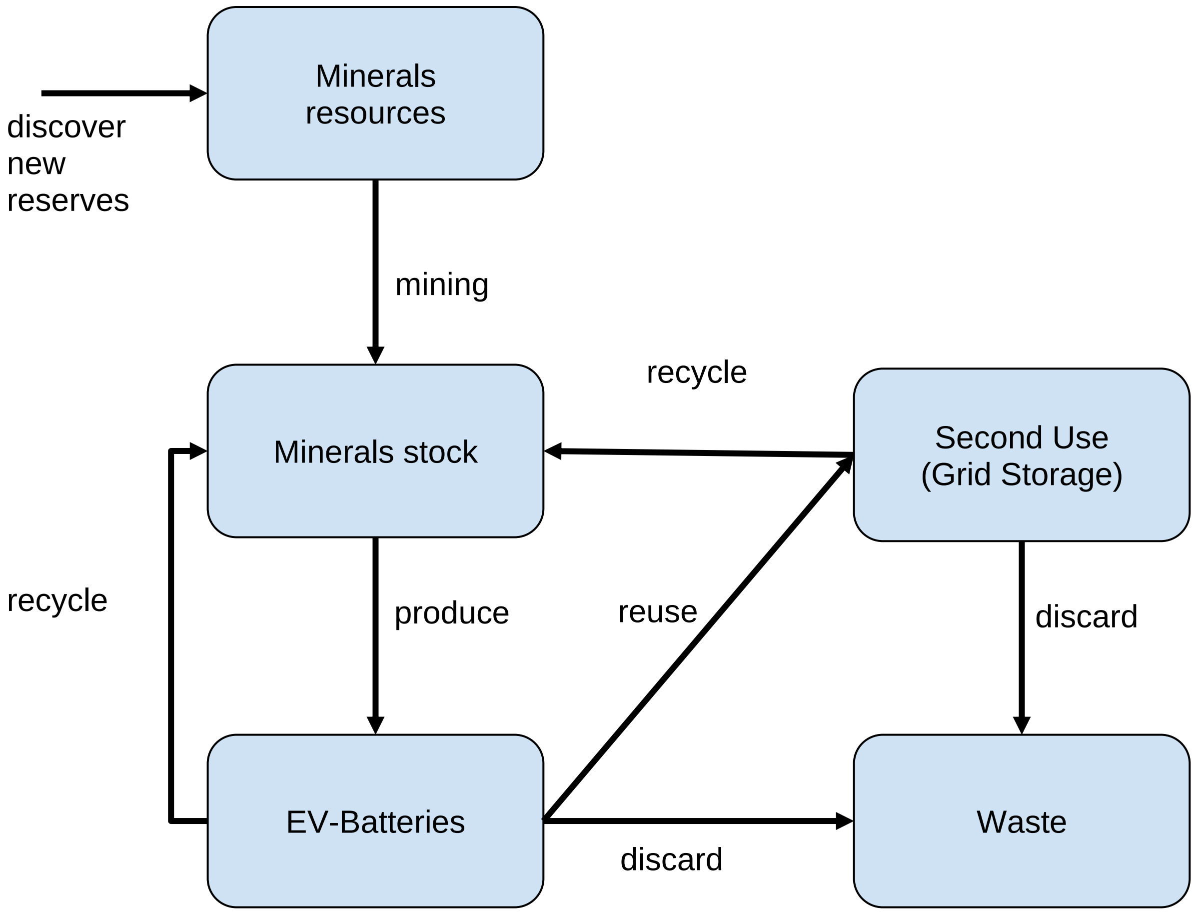

Figure 5: Model Schema

The model operates on an annual cycle, capturing year-over-year changes across each stage of the lifecycle of minerals used in EV batteries. It tracks the journey of minerals from natural reserves to their second life in applications like grid storage, and ultimately to their end in waste if not recycled. This enables us to measure and analyze the flow of resources up until the year 2050 to determine if the mineral stock will be sufficient to meet the growing demand for EV batteries.

Stocks

In this subsection we focus on outlining the different reserves in our model, detailing the initial values assigned to these reserves and the rationale behind these figures. Establishing accurate initial values for each reserve is critical to starting our simulations with a realistic baseline. These initial quantities are derived from a number of sources and data points, ensuring that our simulations start from a well-informed and credible base.

Minerals resources
This stock represents the amount of minerals on earth, which are not mined yet. It's important to recognize that while the Earth contains vast amounts of these minerals, not all can be feasibly or sustainably extracted. Some reserves may be inaccessible or extracting them might require considerable effort and result in significant emissions. The starting

figures are based on the 2022 World Reserves Estimations as detailed in [1], which enumerates the global reserves for each specific mineral.

Mineral stock
This stock represents the amount of minerals available for production (not only for the EV industry). The 2022 Worldwide Reserves estimates draw from the annual U.S. Geological Survey's 2023 Report [1], which outlines all stock values for the US. From these figures, a stock level equivalent to 1% of the estimated resources was inferred.

EV-Batteries
This stock represents the amount of minerals in EV batteries that are in use. The default value assumes 10 Million EVs on the road starting in 2022 [2], with the amount of minerals deduced by using the demand values for minerals stated by the IEA [3]. Batteries in vehicles sold before 2022 may already be nearing the end of their first-life cycle, complicating their inclusion in a forward-looking analysis.

Second Use
This stock represents the amount of minerals in batteries, which have been repurposed after reaching their end of life for usage in an EV. An example for this case would be grid storage. Reports and studies, such as those by McKinsey [4], indicate that the potential for second-life battery applications is significant and growing. However, the exact percentage of EV batteries entering the second-use market by 2022 was not explicitly detailed in these sources due to the emergent nature of these applications and the variability in market development, technological advancements, and regulatory frameworks across different regions. Therefore, we assumed a conservative value of 1% of the EV Stock.

Waste
Not all minerals can be recycled or reused and are wasted. This amount will be stored in this stock. For simplicity's sake the start value was set at zero.

Flows

The provided table outlines each flow in the model. It also specifies the default values assigned to these flows, which are applied when the user does not modify the parameters within the user interface. These default settings ensure the model operates on a standard baseline, enabling users to gauge the impact of their parameter adjustments. To maintain consistency across all stocks' in- and outflows, the flows are measured in kilotons per year [kt/year].

Flow	Description	Default Values	Units
Recycle	Describes recycling process under following assumptions.	Recycling Rate from Stock: 0-10% End of Life Rate EoL: 0-10% (adjustable) Recycling Rate over battery lifespan 40% (adjustable) based on [7] Assumptions for scenario-EU Recycling Rate Over Whole Stock=(Number of Batteries Recycled / Total Battery Stock)×100%	[kt/year]
Repurpose	Reuse for repurposed batteries for instance for grid storage	Repurpose Rate: 0-50% (adjustable) 23% based on [7] Assumptions for scenario-EU	[kt/year]
Discard	Discarded Batteries	Discard Rate: automatically calculated based on Recycle and Repurpose Flows.	[kt/year]
Mining	Yearly Mining Production based on demand predictions:	Nickel: 3'300 kt/yr (2022) Lithium: 130 kt/yr (2022) Cobalt: 190 kt/yr (2022) Based on [1] Production Rate based on US Geological Survey 2012-2022. The Mining Flow can be directly adjusted based on the yearly demand.	[kt/year]
Discover	New Mineral Discovery based on historical data	Discover Rate (constant): Cobalt: 1% Lithium: 7% Nickel: 2% Based on [1] US Geological Survey 2012-2022	[kt/year]
Produce	Minerals Use for Battery Production based on Demand Predictions. A production limit is defined to account for other uses (solar energy, wind, etc.).	Allocated EV Reserves (constant): Stated Policies Scenario - Nickel: max. 35% Reserve - Cobalt: max. 40% Reserve - Lithium: max. 75% Reserve Announced Pledges Scenario - Nickel: max. 50% Reserve - Cobalt: max. 55% Reserve - Lithium: max. 85% Reserve Announced Net Zero Emissions by 2050 Scenario - Nickel: max. 50% Reserve - Cobalt: max. 55% Reserve - Lithium: max. 85% Reserve Based on [8]	[kt/year]

4.2 Model

The model was created using the BPTK_Py python library, guided by established logic in the last chapter. For transparency and reproducibility, the code to the model is available in the following Git repository: https://github.com/dwnflx/ev-battery-dashboard.git.

4.3 Application/User Interface

The application's user interface aims to simplify the complexity of the model's outputs for users while providing them with the ability to customize parameters according to their needs. The screenshot below offers a glimpse of the final version of the app.

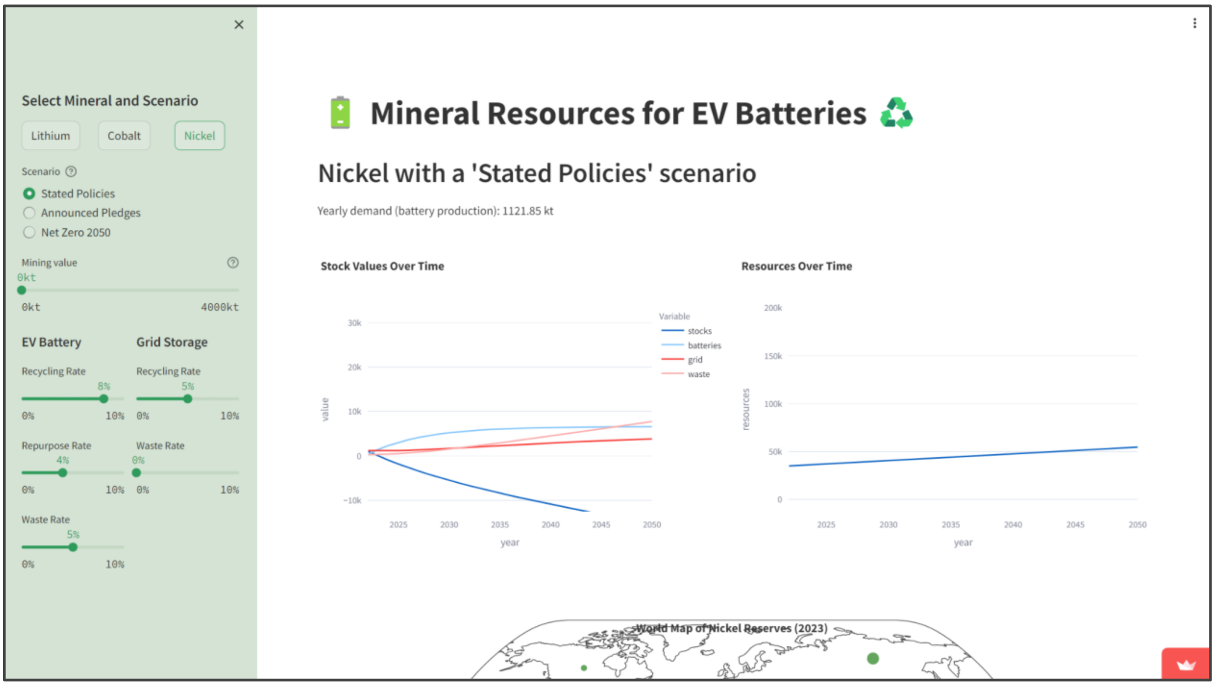

Figure 6: App Screenshot

The application can be accessed by this link: https://ev-battery-dashboard.streamlit.app/

The left panel of the user interface contains all the adjustable parameters required for scenario generation. Users can manipulate these parameters to tailor the scenarios to their specific requirements. The right panel displays the results dynamically in graphical form, adjusting in real-time to reflect changes made to the parameters. As stated in the 'Logic and Assumptions' section, user inputs are limited to realistic and model-appropriate bounds to maintain the integrity of the simulations. In our world map, the estimated global reserves for each mineral are presented by country, drawing upon data from the US Geological Survey. This information is detailed in [1] Mineral Commodity Summaries 2023, published in January 2023.

The source code and additional resources are available on our Git repository. It can be accessed at https://github.com/dwnflx/ev-battery-dashboard.git. This repository provides insight into the application's development process.

5. Conclusion

5.1 Results

Our analysis underscores the importance of developing robust recycling programmes for EV batteries in the coming year. While our projections show that existing reserves of lithium, cobalt and nickel will be able to meet EV demand until 2050 under current scenarios, more ambitious climate policies reveal a risk of depletion if we do not start recycling minerals from EV batteries.

Mineral-Specific Overview

Lithium: Across all three examined scenarios, our analysis indicates that the existing lithium reserves are sufficient to meet EV demands until 2050 without recycling EV batteries. However, beyond this timeline, the available resources are projected to be critically depleted.

Cobalt: For cobalt, reserves are projected to meet demand until the end of 2050 in the "stated policies" scenario, assuming no recycling efforts are made. However, in the "announced pledges" scenario, cobalt resources are projected to be depleted by 2049, and in the "net zero 2050" scenario, depletion is projected as early as 2044 if no recycling measures are implemented.

Nickel: The situation for nickel mirrors that for cobalt. Under the current "stated policies" scenario, nickel reserves meet demand if no recycling takes place. However, under more ambitious climate policies, such as the "announced pledges" and the "net zero 2050" scenario, nickel reserves are projected to be depleted by 2046 and 2041 respectively, requiring the implementation of recycling strategies.

5.2 Limitations

A key challenge in this project was to balance the simplicity of the model with the accuracy of the estimates. While we believe we've struck a reasonable balance, it's important to interpret our figures with caution.

We believe our results accurately reflect trends and indications, although the exact figures should not be taken as definitive. The implementation of time lags was another hurdle, which we overcame by calculating the recycling rate over the years.

Selecting appropriate figures and making informed assumptions was also a complex task. All assumptions were data-driven, but to maintain simplicity and feasibility within the framework of the BTPK library, some adjustments and assumptions were necessary.

Given the one-week timeframe for this project, we are pleased with the outcome. Our model provides solid trend predictions, although the specific figures cannot be projected directly into the future.

5.3 Outlook

In the block week, we successfully crafted a basic prototype. For future enhancements, we're considering the following upgrades:

- Improving the assumptions in the model with expert opinions for instance with the DELPHI method
- Adding more detail to the models to better capture nuances. For example, a better model (not only a constant) for the recycling rate, as it is likely to increase over time as technology advances and becomes more efficient.
- Expanding the app to incorporate broader economic factors beyond the supply chain specifics
- Going beyond mineral stock calculations, we could integrate CO_2 emissions data into the model, which will help in identifying the most significant bottlenecks for a sustainable EV production

These advancements will transform our app into a more thorough and effective tool for analysis and decision-making, contributing significantly to the field of sustainable automotive practices.

5.4 Summary

The research conducted in this report underscores the critical need for sustainable practices in the automotive industry, particularly focusing on the recycling of electric vehicle batteries. Our study, using a system dynamics model, reveals significant insights into the future demands for lithium, nickel, and cobalt, essential components in EV batteries. The simulation, developed using the BPTK_Py python library and visualized through a Streamlit app, offers stakeholders a dynamic tool to forecast and plan for the increasing requirements of these minerals. The app we developed serves a dual purpose: it is a predictive tool for stakeholders to simulate various scenarios and an educational platform for raising awareness about the necessity of efficient recycling systems in the EV industry. By providing an interactive and user-friendly interface, the app encourages users to explore different outcomes and understand the impact of their decisions on the future availability of critical minerals.

However, we approach our findings with a degree of caution. While our model is extensive, it is founded upon current data and assumptions that are likely to evolve with advancements in technology and policy changes. Additionally, due to the unavailability of precise predictions for each stock and flow, some assumptions made by our team may require future adjustments. The adaptability of our model, powered by the BPTK_Py library, allows for continuous updates and refinements, assuring its ongoing relevance and accuracy. In conclusion, this report and its accompanying app emphasize the need for immediate action in the field of EV battery recycling. By highlighting the potential shortages of critical minerals and offering a platform for exploring solutions, we aim to catalyze industry and policy changes towards a more sustainable and environmentally conscious future in the automotive sector. The challenge now lies in translating these insights into practical, effective strategies for mineral conservation and recycling, ensuring that the EV revolution contributes positively to our planet's health and resources.

6. References

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