Group 6-Transportation Electrification
Bailey Greene
Chia Wen Cheng
Emma Elizabeth Stark
Taylor Valentine

Group Project Deliverable #3: Nonlinearity

Due: March 10th at 5pm

Background: Nonlinear relationships are key drivers to the behaviors from dynamic systems. For the third interim deliverable for the group project, you will formulate at least two nonlinear relationships between variables in your system.

Objective: Identify and model at least two nonlinear relationships in your system. Describe and justify how you formulated these relationships based on available information. Build out your Vensim model to see how these nonlinear relationships impact your system's behavior.

Guidelines: You may wish to further revise your CLD, dynamic hypothesis, and FCM. Modeling is iterative, so do consider how you can improve all of these things as we add new elements to your model.

When you have identified two variables that are related by a nonlinear relationship, collect any data, information, and intuition that is available on this relationship. For many of your nonlinear relationships, you will want to develop a graphical function (as opposed to an analytic function) to effectively represent the full range of the nonlinear relationship. You will typically want to normalize the input and output, identify reference points and policies, consider extreme conditions, evaluate the full range of possible values for the independent variable, and identify plausible shapes for the relationship.

To examine the impact of the nonlinear relationships, you should build a simple Vensim model that features the variables associated with the loop(s) that contain the non-linear relationships. This will likely be only a piece of your full CLD/FCM and not a complete representation of your full system. That is okay for this deliverable, as our objective here is to get experience formulating nonlinearities. Use your (partial) model to show some variables' behavior over time, as influenced by these nonlinearities. Provide a short, written description (~1 paragraph) in which you interpret these results.

For the nonlinear relationships in your system that you identify, provide a written description of how you formulated them, summarize the data, information, and assumptions made (with appropriate citations). The written description of the nonlinear relationships, the data, and any assumptions that you make can be brief (~1-2 paragraphs per nonlinearity, plus a table if helpful). You should also include a screenshot of the graphical functions that you developed. (Note: if you opted to develop an analytic nonlinear function, you may present the relevant equation(s) instead.)

Bailey Greene
Chia Wen Cheng
Emma Elizabeth Stark
Taylor Valentine

Deliverables: Your assignment submission should include
(1) any content from the previous interim deliverables that have been revised;
(2) text (and a table if helpful) describing how you formulated the nonlinearities that you are investigating, as well as the data, information, or intuition that you used;
(3) screenshots of the graphical functions that you developed (pasted into the Word Doc or PDF; if you opted for an analytic function, you may present the associated equation);
(4) a screenshot of the Vensim model's system structure (pasted into the Word Doc or PDF); and
(5) graphs showing the behavior over time for variables impacted by the nonlinearities (again, pasted into the Doc or PDF).

Taylor- think through another nonlinearity example, write paragraph
Emma- start models
Bailey- revision for CLD- person to submit
Chia Wen- look over, FCM revision

Research focus: subsidies/policy, battery recycling, lithium extraction

Rubric Criteria:

- Identified two nonlinear relationships. A screenshot of the Vensim model is included and the links between variables are logical.
- Includes a concise explanation of each non-linearity and a summary of the data, intuition, and/or information used to formulate the relationships.
- Includes a screenshot of both graphical functions (or an analytical equation) that illustrates the non-linearity of the relationships.
- Includes at least one graph for each nonlinear relationship, which shows the behavior of the variables impacted by the non-linearities, and a short, written description interpreting the results.
- The concepts and relationships not directly involved in the nonlinear relationships are well defined and backed by research/data.

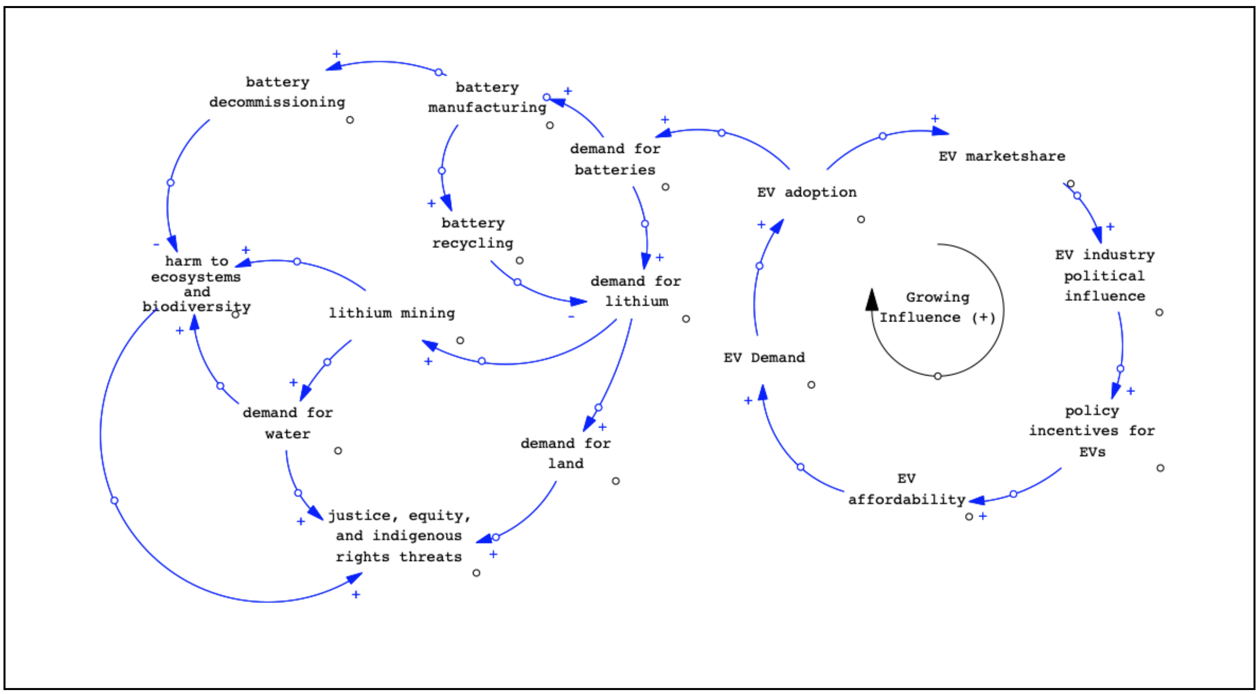
Things to do:

- Revised content from previous deliverables
    - Should we limit our scope to the US- global supply chain, but political influence/EV purchases/etc limited to the US? Could make finding data a bit easier
- Description of formulated nonlinearities (identify 2); include data, information or intuition used
    - Increase of EVs purchased after subsidy deployed

- Some subsidies only apply up to a certain amount of EVs sold, we might have to look into a specific subsidy to get accurate data
  - EV adoption and presence of air pollution
    - Might have to assume all other factors remain the same
      - I.e., electric vehicle manufacturing occurring elsewhere
- Screenshots of graphical functions (or analytical equations)
- Screenshot of Vensim model structure
- Graphs for each nonlinearity showing behavior over time of variables impacted by nonlinearities

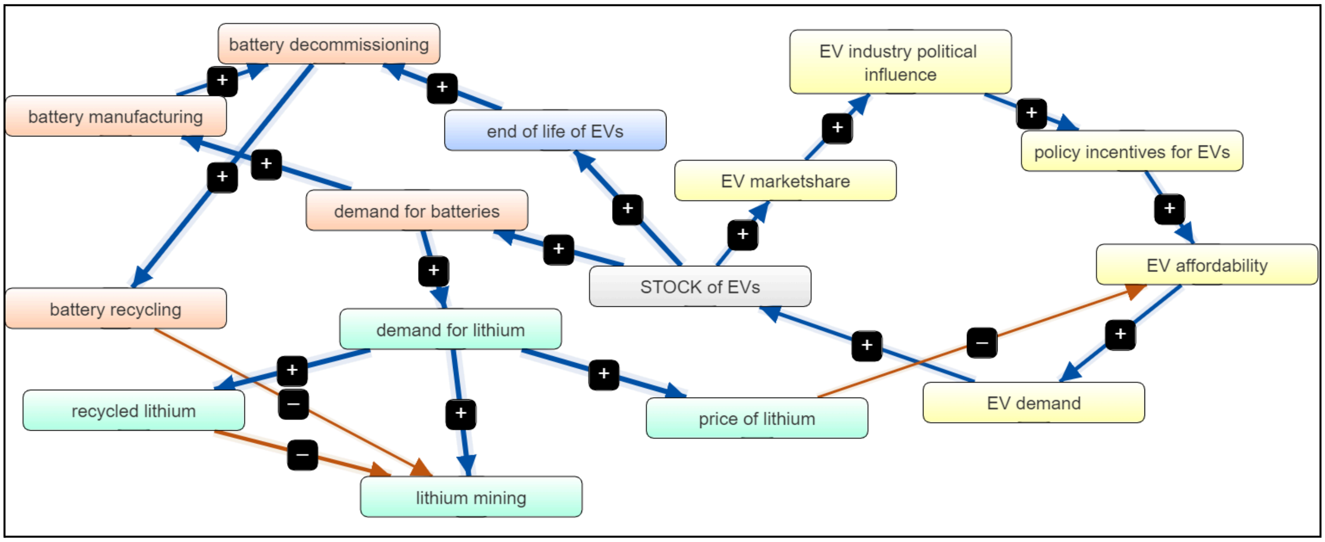
Revised Content

CLD



Group 6-Transportation Electrification
Bailey Greene
Chia Wen Cheng
Emma Elizabeth Stark
Taylor Valentine

FCM



The revised CLD and FCM to show our focus on the EV market, use of battery, and lithium mining. We also limited our scope to the US for easier and more detailed research work. This is further shown in our revised dynamic hypothesis below.

Dynamic hypothesis

Electric vehicles (EV) are creating a cutting edge in the field of technology and automobiles. Public policy provides direct incentives for the market of EVs to grow, increasing consumer demand for EV products and derivatives, enhancing the needs of lithium in batteries, and boosting industry political influence for advocacy. Used battery recycling contributes to environmental sustainability uncertainty, while maintenance and public budgeting draw financial and social sustainability interests. Humanity topics proposed in this dynamic system include justice/equity and indigenous rights which simultaneously push concerns of international sourcing of rare minerals to the table.

Formulating the Non-Linearity

We identified two non-linearity relationships: 1) policy intervention and stock of EVs; and 2) demands for lithium and EVs.

Policy Non-Linearity

- Assumption that drivers are switching from Internal Combustion Engine Vehicles (ICE) to EV
  - Not purchasing an EV without retiring an ICE
- Stock of fully electric vehicles in the US as of 2021= 1.3 million

Year	New EV Sales (millions)	Stock of EV (millions)
2016	0.15	0.57
2017	0.19	0.76
2018	0.35	1.11
2019	0.30	1.41
2020	0.32	1.73
2021	0.64	2.37
2022	0.77	3.14
2023	0.95	4.09
2024	1.16	5.25
2025	1.42	6.67
2026	1.74	8.41
2027	2.13	10.54

  - Source: https://www.statista.com/outlook/mmo/electric-vehicles/united-states#unit-sales
  - https://www.iea.org/reports/global-ev-outlook-2020
- Stock of ICE light duty vehicles as of 2021= 118.074303 million
  - Source: https://www.eia.gov/opendata/v1/qb.php?category=2118520&sdid=AEO.2016.HIGHMACRO.ECI_STK_TRN_CAR_CNV_NA_NA_MILL.A
- Tax credit =$7,500
  - Source: https://www.irs.gov/credits-deductions/credits-for-new-clean-vehicles-purchased-in-2023-or-after
- Average Cost of EV in 2021

Year	Cost (thousands)	Annual Purchase (millions)
2016	70.64	0.15
2017	70.23	0.19
2018	69.82	0.35
2019	69.41	0.30

2020	69	0.32
2021	68.59	0.64

- Source: https://www.statista.com/outlook/mmo/electric-vehicles/united-states#price

- Lifespan of EV= 12 years
  - Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9171403/

Lithium Demand and EV Demand Non-Linearity

- Lithium Demand

Year	Demand (Thousand Metric Tons)
2019	263
2020	327
2021*	465
2022	559
2023	685
2024	838
2025	1,003
2026	1,169
2027	1,349
2028	1,560
2029	1,831
2030	2,114

  - Source: https://www.statista.com/statistics/452025/projected-total-demand-for-lithium-globally/

- Unit Sales

Year	EV Sales (millions)
2016	0.15
2017	0.19
2018	0.35
2019	0.30

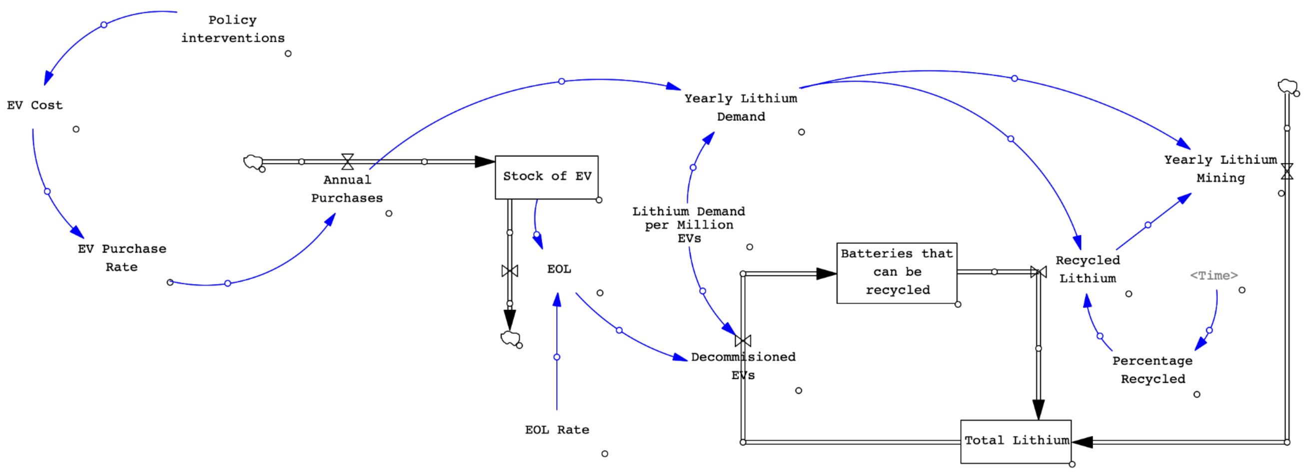
2020	0.32
2021	0.64
2022	0.77
2023	0.95
2024	1.16
2025	1.42
2026	1.74
2027	2.13

- Source: https://www.statista.com/outlook/mmo/electric-vehicles/united-states#unit-sales

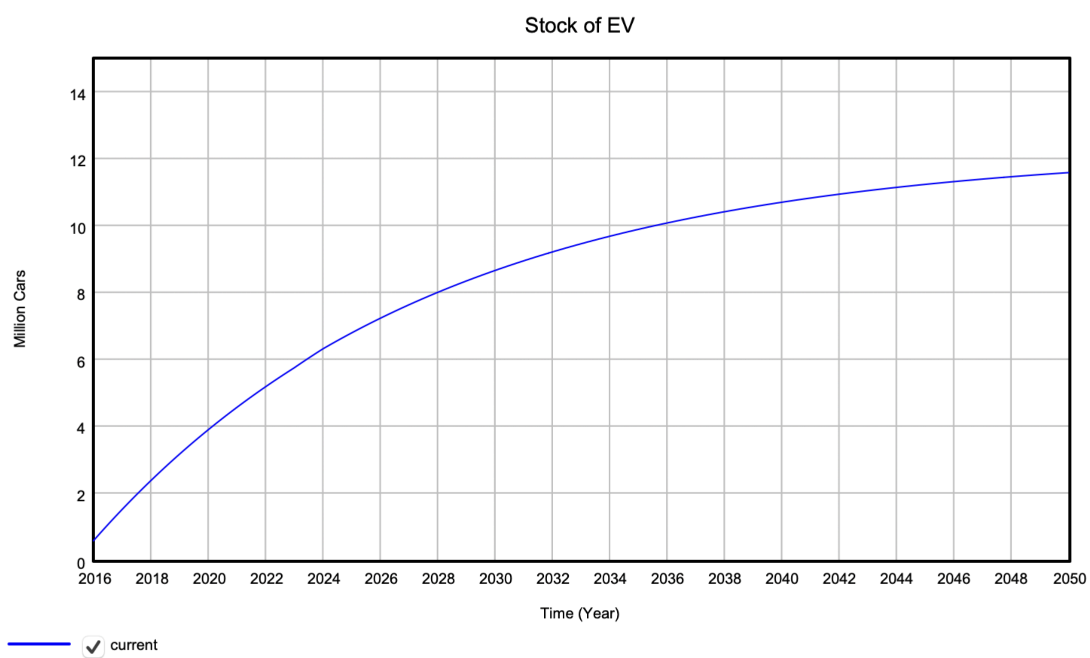
Associated Equations

- **Policy Interventions:** 7.5+PULSE(2023 , 1) *Thousands*
- **EV Cost:** 70.64-Policy interventions *Thousands*
- **EV Purchase Rate:** WITH LOOKUP (EV Cost) ([(0,0)-(100,4)],(0,3.3),(20,2.5),(48,1.6),(68.59,0.64),(69,0.32),(69.41,0.3),(69.82, 0.35),(80,0.01),(100,0))
- **Annual Purchases:** EV Purchase Rate
- **Stock of EV:** Annual Purchases-EOL *Million Cars*
- **EOL:** EOL Rate*Stock of EV
- **EOL Rate:** 0.083
- **Decommissioned EVs:** EOL*Lithium Demand per Million EVs
- **Lithium Demand per Million EVs:** 8.8 *KT*
- **Yearly Lithium Demand:** Annual Purchases*Lithium Demand per Million EVs *KT*
- **Batteries That Can Be Recycled:** Decommissioned EVs-Recycled Lithium *KT*
- **Total Lithium:** Recycled Lithium+Yearly Lithium Mining-Decommisioned EVs *KT*, initial value of 77
- **Yearly Lithium Mining:** Yearly Lithium Demand-Recycled Lithium *KT*
- **Recycled Lithium:** Percentage Recycled*Yearly Lithium Demand
- **Percentage Recycled:** WITH LOOKUP (Time) ([(0,0)-(50,10)],(0,0),(2026,0.06),(2036,0.12),(2046,0.18),(2056,0.24),(2066,0.3))

Vensim Model's System Structure and Non-Linear Impacts

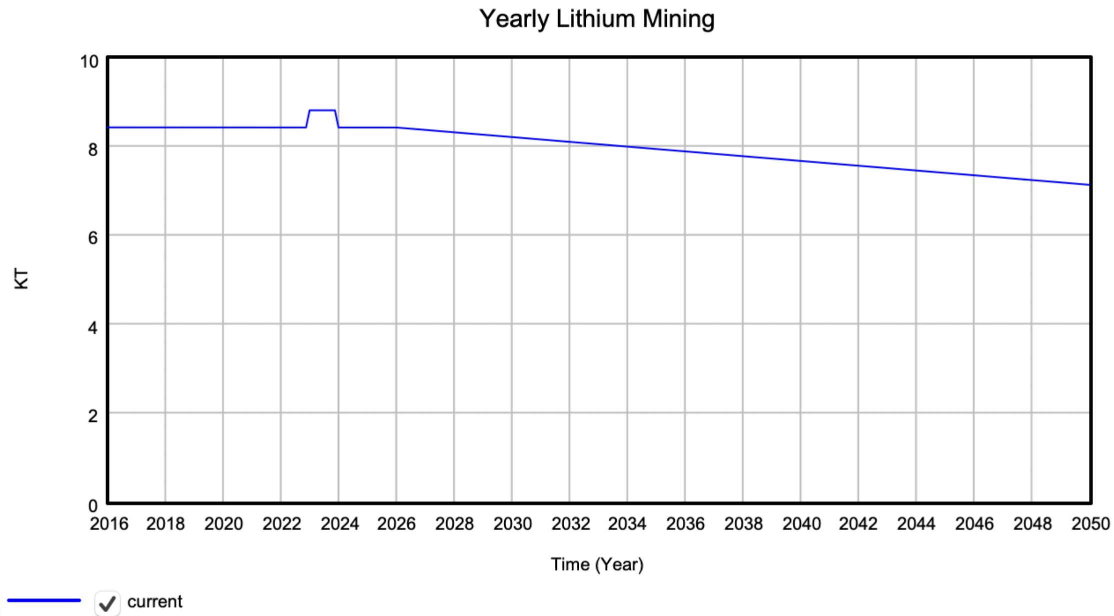


1. Policy Intervention and Stock of EV



The total stock of EVs in the US is reflective of the impact of a one-year, $7,500 subsidy implemented in 2023. The subsidy value is based on a current tax credit that is offered [1]. The end-of-life rate is based on findings that EVs last on average for 12 years on a single battery [2]. The average EV cost in 2016 was $70,640 [3]. The annual purchase rate is based on historic trends in EV sales [3]. The starting stock of EVs in 2016 was .57 million vehicles [3].

2. Yearly Lithium Mining and Total Lithium



The projected trend of the amount of lithium mined annually in kilotons (KT) is reflective of the one-year $7,500 subsidy that grew annual purchases and the projected increase in lithium recycling capacity at 6% every ten years [4]. The 2016 level of lithium demand of 77 KT is based on figures from the "Global EV Outlook 2020" report [4]. The amount of lithium per million electric vehicles is 8.8 kt [5].

Sources:

1. https://www.irs.gov/credits-deductions/credits-for-new-clean-vehicles-purchased-in-2023-or-after
2. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9171403/
3. https://www.statista.com/outlook/mmo/electric-vehicles/united-states#price
4. https://www.iea.org/reports/global-ev-outlook-2020
5. https://www.weforum.org/agenda/2022/07/electric-vehicles-world-enough-lithium-resources/