Group 6-Transportation Electrification
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EAS 550/STRAT 566 Systems Thinking for Sustainable Development & EnterpriseFinal Project Deliverable #2: Fuzzy Cognitive Map and Scenario Testing
Due: February 17th at 5pm

Background: You have scoped and outlined key elements and relationships in your system. For the second interim deliverable, you will create an FCM which you will use to test system dynamics.

Objective: Create a fuzzy cognitive map of your system, based on your CLD and any additional research that is needed. Define connections strengths and run at least two scenarios that test system dynamics related to your dynamic hypothesis.

Guidelines: You may have received feedback on your CLD and dynamic hypothesis which warrant some edits and improvements. In addition, your team's ideas for the project may have changed or shifted. Modeling is an iterative process and making changes throughout will improve your overall model and make the interim deliverables more useful and productive.

To create the FCM, use the more recent CLD as the basis for system structure and create a model in MentalModeler. Using your previous research on your system and any additional information needed, parameterize the model by addition connection strengths. To guide this process, have a well-defined understanding within your group about how connection strengths are determined and what different strengths mean. This can be a qualitative, quantitative or hybrid process. Your FCM should follow the conventions discussed in class. For example, make sure you are using the "hyperbolic tangent" function in MentalModeler.

Next, you are going to test your FCM by running at least two "what-if" scenarios. The first should be formulated to test your hypothesis from ITD 1. You should discuss how your hypothesis relates to FCM scenario outcomes. The second scenario is up to your group but should assist in the modeling process. For example, you could formulate a scenario that helps test the sensitivity of the model or creates a prediction of outcomes based on an intervention. For this scenario, you should clearly describe the learning goal of the test.

Deliverables: Your assignment submission should include (1) any revised content from your first interim deliverable; (2) a screenshot of your completed FCM (created in MentalModeler) and description of how connection strengths were determined/attributed to the model; (3) a description of each scenario that was conducted, including justification/reasoning for the scenario (i.e. what are you testing and why?) and the specific scenario conditions (what components are being clamped and what value are they being clamped at); and (4) scenario results (bar graph from MentalModeler) and 4-5 sentences of interpretation of results.

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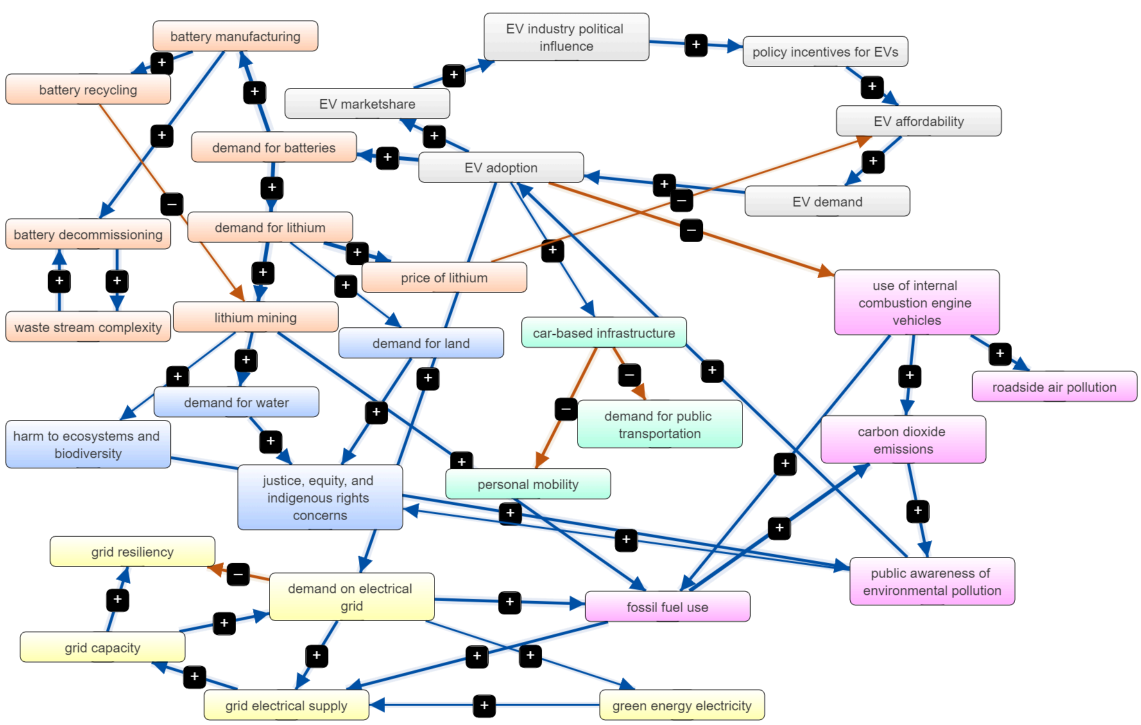
Rubric Criteria:

- The process of assigning connection strengths is clear and defensible.
- The fuzzy cognitive map includes accurate and justified strengths and polarities.
- Variable names are nouns with a clear sense of direction and the map is laid out clearly.
- The dynamic hypothesis scenario is logical, and the results correctly interpreted
- The second scenario clearly tests a useful dynamic of the system and has correctly interpreted results.

Revised Content

We changed the connection from “grid capacity” to “demand on the electrical grid” from negative to positive since greater supply of electricity should ideally increase demand for it. We also added a variable “public awareness to environmental pollution,” which is positively connected by “harm to ecosystems and biodiversity” and “carbon dioxide emissions,” and connects positively with “justice, equity, indigenous rights concerns” and “EV adoption.” “Price of lithium” was added to the model because it is affected by and in the same direction as “demand for lithium” economically, and will cause a reduction in “EV affordability” once the price goes up. Last but not least, we realized that more “lithium mining” will increase “fossil fuel use,” and thus include this relationship to the model to better reflect the complexity of our topic.

FCM from MentalModeler



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Connection strengths are determined by additional research described as the following:

- Policy incentives for EVs →+ EV affordability = 0.5[1]
    - Credit up to $7,500
    - Limits to those who qualify
- EV adoption →+ Demand for batteries = 0.9[2]
    - Battery demand to increase by 30% by 2030
    - 90% of battery demand will come from mobility applications
- Demand for batteries →+ Demand for lithium = 0.9[3]
    - Combustion engine cars do not use any lithium while EVs use 8.9 kg per vehicle
    - Demand for lithium to increase by 90% over next two decades
    - EVs and batteries are the largest consumer of lithium
- Demand for lithium →+ Price of lithium = 0.9[4]
    - Raw lithium price is expected to increase
- Price of lithium →- EV affordability = -0.25[5]
    - Increased price of lithium could decrease EV affordability
- Demand for lithium→+ Lithium Mining = 0.9[6]
    - With the lithium recycling sector still in its infancy, demand for lithium will greatly increase lithium mining
    - High concentration of mining in China
- Lithium mining →+ Demand for water = 0.5[7]
    - A water intensive practice, 50% of lithium mining and production occurs in areas of high water stress
        - Australia and Chile
- Battery Recycling →- Lithium mining = -0.25[8]
    - Overtime lithium recycling will decrease the need for lithium mining
- Demand for batteries →+ Battery Manufacturing = 0.9[9]
    - Battery demand to increase by 30% by 2030

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[1] The Internal Revenue Service of the United States. Credits for New Clean Vehicles Purchased in 2023 or After. Retrieved on February 15, 2023, from https://www.irs.gov/credits-deductions/credits-for-new-clean-vehicles-purchased-in-2023-or-after.

[2] Andreas Breiter, Evan Horetsky, Martin Linder, and Raphael Rettig. (October 2022.) Power spike: How battery makers can respond to surging demand from EVs. McKinsey & Company. Retrieved on February 15, 2023, from https://www.mckinsey.com/capabilities/operations/our-insights/power-spike-how-battery-makers-can-respond-to-surging-demand-from-evs.

[3] International Energy Agency. (May 2021.) The Role of Critical Minerals in Clean Energy Transitions. World Energy Outlook Special Report. Retrieved on February 15, 2023, from https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/executive-summary.

[4] Ibid.

[5] Ibid.

[6] Ibid.

[7] Ibid.

[8] Ibid.

[9] The Internal Revenue Service of the United States. Credits for New Clean Vehicles Purchased in 2023 or After. Retrieved on February 15, 2023, from https://www.irs.gov/credits-deductions/credits-for-new-clean-vehicles-purchased-in-2023-or-after.

   - 90% of battery demand will come from mobility applications
- Use of internal combustion engines →+ Roadside air pollution = 0.5[10] [11] [12]
   - In the US, the transportation sector contributes 27% of annual GHG
   - Every gallon of gasoline burned creates about 8,887 grams of CO_2
- Use of internal combustion engines →+ Carbon Dioxide Emissions = 0.5[13] [14]
   - In the US, the transportation sector contributes 27% of annual GHG
   - Every gallon of gasoline burned creates about 8,887 grams of CO_2
- Fossil Fuel Use →+ Grid Electrical Supply = 0.5[15] [16]
   - 25% of GHG emissions in US
   - About 61% of this electricity generation was from fossil fuels—coal, natural gas, petroleum, and other gases.
- Green Energy Electricity →+ Grid Electrical Supply = 0.25[17]
   - Only 19% of US electricity grid comes from renewables
- EV adoption →+ Demand on electrical grid = 0.5[18]
   - Projected to increase demand by up to 38% by 2050
- Lithium Mining →+ Harm to ecosystem and biodiversity = 0.25[19]
   - One study showed slow environmental degradation associated with lithium mining in Chile including faster than avg temp rise, vegetation degradation, and increased drought conditions

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[10] United States Environmental Protection Agency. (May 2022.) Carbon Pollution from Transportation. Retrieved on February 15, 2023, from https://www.epa.gov/transportation-air-pollution-and-climate-change/carbon-pollution-transportation.
[11] United States Environmental Protection Agency. (June 2022.) Greenhouse Gas Emissions from a Typical Passenger Vehicle. Retrieved on February 15, 2023, from https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle.
[12] Andrew Nickischer. (April 2020.) Environmental Impacts of Internal Combustion Engines and Electric Battery Vehicles. *D.U.Quark, 4 (2).* Retrieved from https://dsc.duq.edu/cgi/viewcontent.cgi?article=1068&context=duquark.
[13] Ibid.
[14] Ibid.
[15] United States Environmental Protection Agency. (August 2022.) Sources of Greenhouse Gas Emissions. Retrieved on February 15, 2023, from https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.
[16] U.S. Energy Information Administration. (November 2022.) FAQs-What is U.S. electricity generation by energy source? Retrieved on February 15, 2023, from https://www.eia.gov/tools/faqs/faq.php?id=427&t=3#:~:text=In%202021%2C%20about%204%2C108%20billion,facilities%20in%20the%20United%20States.&text=About%2061%25%20of%20this%20electricity,%2C%20petroleum%2C%20and%20other%20gases.
[17] Ibid.
[18] Alex Brown. (January 2020.) Electric Cars Will Challenge State Power Grids. Pew Charitable Trusts. Retrieved on February 15, 2023, from https://www.pewtrusts.org/en/research-and-analysis/blogs/stateline/2020/01/09/electric-cars-will-challenge-state-power-grids.
[19] Wenjuan Liu, Datu B. Agusdinata, Soe W. Myint. (August 2019.) Spatiotemporal patterns of lithium mining and environmental degradation in the Atacama Salt Flat, Chile. *International Journal of Applied Earth Observation and Geoinformation*, 80: 145-156. Retrieved from https://www.sciencedirect.com/science/article/pii/S0303243419300996.

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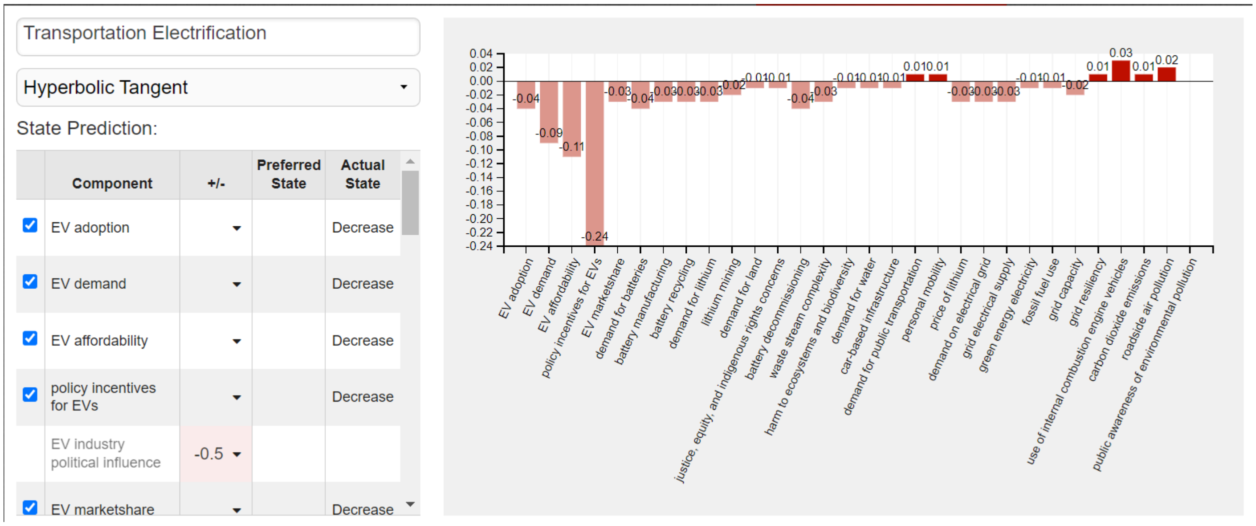
Description of Hypothetical Scenarios and Test Results

1. Effect on EV demand as political influence decreases by 50%

Our hypothesis states that increasing public policy initiatives (i.e., subsidies) to promote the EV market will increase EV demand. To explore the role of EV producers' political influence on public policy initiatives, we ran a scenario where their influence decreases by 50%. We chose to decrease influence by 50% as this is reflective of the current instability of major EV producers like Tesla and Rivian, as showcased by workforce layoffs, while a 100% reduction in political influence was unrealistic.

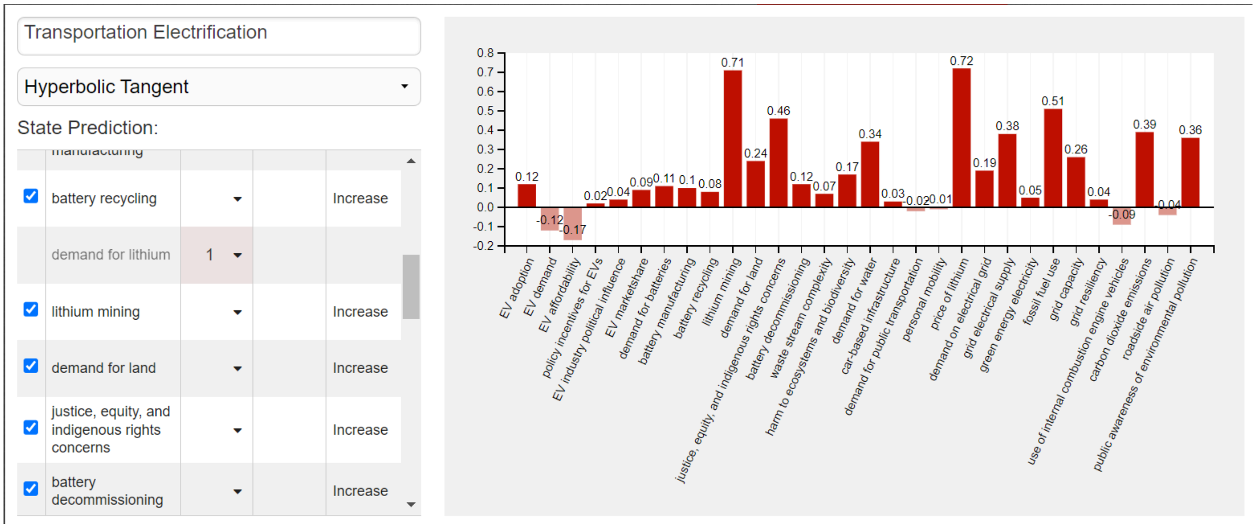


Results

This scenario resulted in a sharp decline in public policy initiatives that, in turn, decreased EV demand. EV adoption decreased a small amount and EV affordability also decreased a notable amount. Interestingly, the demand for internal combustion engine vehicles increased, but not to the same extent. Another interesting outcome from this scenario was that even though EV demand decreased a large amount, lithium mining only decreased a small amount.

2. Effect on justice, equity, and indigenous rights concerns as demand for lithium increases by 100%

Our hypothesis also considers the social and environmental impacts of a growing demand for lithium. We chose to run this scenario as a 100% increase in demand as market projections expect lithium demand to increase by about this much over the next two decades[3].

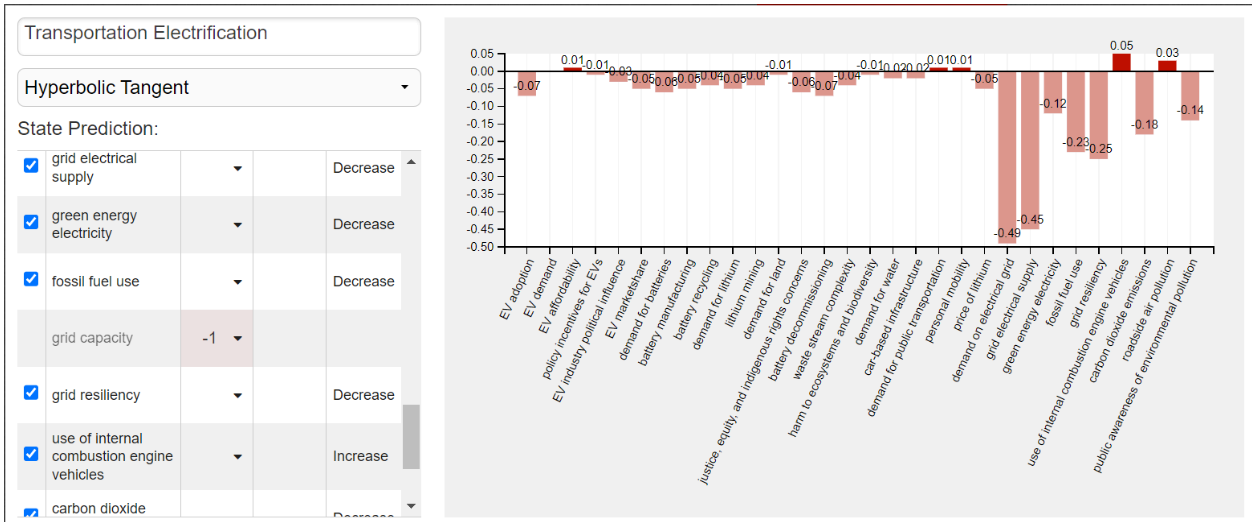


Results

The results of this scenario shows that as the demand for lithium increases, the justice, equity, and indigenous rights concerns increase. An interesting result is as EV demand decreases, EV adoption increases. One could speculate that outside factors like more secondhand EVs entering the system could cause this, but this result is not congruent with our expectations and will have to be looked into further. In the future, it would be interesting to run a scenario where lithium demand increases while battery waste stream complexities decrease to understand how much recycling will need to occur for lithium mining to also decrease.

3. Effect on EV adoption as grid capacity decreases by 100%

We are interested in exploring the potential consequences of the electricity grid being damaged due to accidents such as explosions, and capacity rapidly decreasing. Setting the value of impact to 100% is extreme, as we were simulating damages that may require numeral years of recovery and repairment.

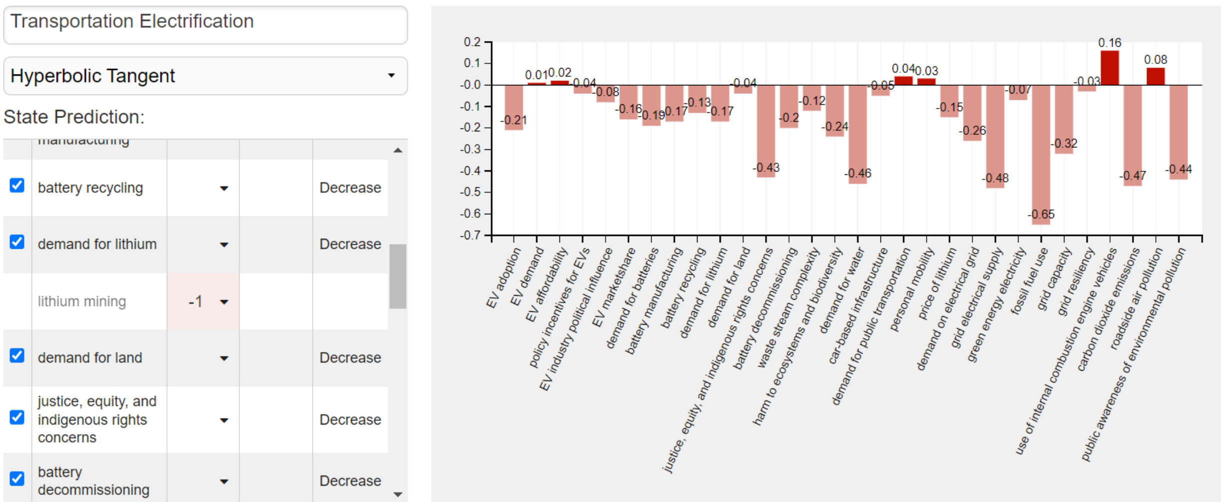


Results

This large decrease in grid capacity caused a small decrease in EV adoption, but large decreases in grid supply and resiliency. It also produced a lot of interesting results, including as capacity decreased, so did demand on the grid. This seems counterintuitive as one would expect demand to remain the same even as capacity decreases. This result highlights the challenges of interpreting an FCM where no timescale is assigned. In the future, we should re-run this scenario over a variety of timescales to get a more accurate understanding of a rapid grid capacity decrease.

4. **Effect on demand for public transportation as lithium mining decreases by 100% (was banned)**

   This scenario was run to explore the impacts on the EV market if lithium mining were to stop completely. We assumed this would drastically reduce EV adoption as battery manufacturing would be brought to a standstill unless battery recycling increased drastically. Followed by the decrease in EV adoption, demand for public transportation is presumably to increase since EV is by nature a substitution to public transportation.



Results

The results confirmed our hypothesis that as lithium mining decreases, demand for public transportation will increase. An interesting point we would like to mention is the reduction in justice, equity, and indigenous rights concerns. Variables related to development may be more impactful to the humanity concerns we care about in our model than the other justice impedes raised by pollution issues. This again highlighted the obstacle of interpreting an FCM in which the timeline is not properly designated. In the future, we would like to re-run this scenario over a variety of timescales to get a more accurate estimation on humanity concerns.