Week 5 assignment, MFA2, 2024

This week you'll work in a group to create a dynamic MFA Python code to model scenarios of different sorts.

Form 4 groups, each group with a maximum of 5 students. Each group gets a type of scenario of resource efficiency strategy to model. Each group should work independently of the others.

Next week we'll post your codes and our codes to Brightspace as a library of codes that you can mix & match for your own future work.

Even though you work as a group, as usual don't forget to submit your assignment (code and presentation file) individually and indicate who you worked with in your group. When our results are published the day before next class, don't forget to study the codes for all scenarios because we expect you to know how to apply all types of scenarios by the end of this course.

There are some useful modeling & coding tips in the bottom of this document about plotting figures, loading multiple excel sheets, interpolations, etc. We highly recommend using these tips!

Data, assumptions, and baseline scenario for all groups

The data and basic assumptions are modified from Fishman et al. (2018). That study explored the flows and stocks of metals used in alternative-energy vehicles (hybrid, electric, fuel cells…) in the USA from the first ones sold way back in 1998 to various futures toward 2050.

Our simplified baseline scenario is:

- In-use alt. energy vehicle stocks will grow in an s-shape and reach 103,125,124 vehicles in 2050.
  The stock growth timeseries is in vehicles.xlsx sheet *stocks*.

- All historical and future alt. energy vehicles are hybrid vehicles (HEV) with NiMH batteries.
  The material intensities (MIs) of this vehicle type, as well as the other vehicles' MIs, are in vehicles.xlsx sheet *material_intensities*.

- Alt. energy vehicles of all types and from all years follow the same survival curve. The median life expectancy is 14.57 years (i.e. 50% of the cohort survives to this age), and there's a long tail of very old surviving cars (Apparently Americans like their cars). This survival curve is described by a Weibull distribution survival function with a shape parameter = 2.428914875 and scale parameter = 16.93851375.
  These parameters are in vehicles.xlsx sheet *survival_weibull*.

- No recycling of metals from end-of-life vehicles, so all inflows are virgin materials.

- We are interested in the flows and stocks of vehicles (in units), and steel and aluminum (in mass).

From this you should be able to tell that we'll need a stock-driven model for the vehicle flows, that feeds to a second model for the corresponding material flows and stocks.

You can use our code (vehicles_baseline.py) though we recommend to create your own because it's good practice. You can compare your baseline code's results to the ones from vehicles_baseline.py to make sure that your code works successfully.

Group scenarios – resource efficiency strategies

There are two scenarios for you to code in your group. Scenario A is a basic scenario in which one parameter changes one time compared to the baseline, sort of like turning it on or off. Scenario B is a more advanced scenario in which the same parameter changes gradually over time. Each scenario should be a variant of the baseline scenario, not of each other.

Your group should prepare a simple presentation with 3 slides:

1. The group scenario description. You can copy it from here, though a visualization would be a valuable addition.
2. Model diagram, like the examples in this week's slides, and the ones you did in week 3's homework.
3. Results of the baseline scenario vs. the two new scenarios. Must compare the inflows, outflows, and stocks of vehicles and of the materials specified in the scenarios. The recycling scenario has other indicators to present. Optionally, compare further indicators such as expansion / maintenance, stock or outflow composition, and any other variables that you find interesting.

Group 1: Material substitution

A new aluminum-cerium alloy (Sims et al., 2022) becomes available in 2025 that can replace steel in multiple applications in vehicles. Hybrid vehicles with the new alloy have these MIs: New aluminum MI = 154073.40 , new steel MI = 911804.25

Scenario 1A: The new alloy is extremely successful, and all vehicles sold from 2025 have the new material intensities

Scenario 1B: The new alloy is gradually introduced to the market. in 2025, 1% of new cars have the new MIs, growing linearly to 50% of new cars sold in 2050. The rest have the original MIs.

Calculate both steel and aluminum results.

Group 2: Steel recycling

Scenario 2A: what if end-of-life steel recycling was implemented from the start? How much virgin material could we have saved? In this scenario, 60% of the steel outflows of every year 1998-2050 are recycled to become inflows in the same year. Therefore, the remaining demand for inflow must be sourced from virgin materials: *inflow = recycled + virgin materials*.

Scenario 2B: what if steel recycling only started in 2005, but it ramps up quickly and will reach its maximum potential of 70% in 35 years. In other words, the ratio of outflows that go to recycling increases linearly from 0% in 2005 to 70% in 2040 and remains at that level until 2050. As in the basic scenario, recycled steel becomes inflow in the same year and the remaining demand is virgin material.

Only calculate steel results. Beside the usual flows & stocks results, calculate and present the following extra columns:

- The recycled materials
- Virgin material demand
- The circular material use rate (CMU) : *recycled material / total inflows* (Mayer et al., 2019)

Groups 3: vehicle type substitution

Scenario 3A: what if 40% of vehicle stocks 1998-2050 were all-electric vehicles (AEVs) with Li-ion batteries, and HEVs were 60% of the stock? What would be the inflows and outflows of HEVs and AEVs, and how would this affect total aluminum flows and stocks?

Scenario 3B: what if fuel cell vehicles with Li-ion batteries appear on the market in 2031 and aggressively increase market share, so that by 2050 FCVs form 30% of the stocks? In other words, all vehicles stocks 1998-2030 are HEVs, in 2031 FCVs are 1% of the stock, and they increase linearly to 30% of the stock in 2050.

Only calculate aluminum results.

Groups 4: lifetime extension

Scenario 4A: A new economic policy is implemented in 2025 to encourages longer use of vehicles. All HEVs sold from 2025 onward get subsidies and partial refunds if they are used for a longer time. From 2025 on, new cohorts have a median of 20 years, though the shape of the survival curve is the same as before. Therefore, the survival curves of inflow cohorts from 2025 onward have a scale parameter of 23.25751, and the shape parameter is unchanged at 2.428914875.

Scenario 4B: Vehicles in the USA are actually being used longer and longer, though this is not described in the baseline scenario. In this scenario, we assume that vehicle lifetimes will continue getting longer in the future naturally. The survival curve's scale parameter increases linearly from the original value of 16.93851375 in 1998 to 25.58326 in 2050 (which is equivalent to a median of 22 years). The shape parameter is unchanged at 2.428914875 throughout.

Calculate either aluminum or steel results.

Important tips – read these!

- Draw the diagram of your model before you start coding, and use it as a roadmap to what you want to achieve.

- Refer back to this week's slides, especially the last ones about scenarios in dynamic MFA and the slide with general description of this assignment.

- You can load different sheets into a dataframe by adding the *sheet='sheet_name'* argument to pd.read_excel() . There are other useful arguments that you can add https://pandas.pydata.org/pandas-docs/stable/reference/api/pandas.read_excel.html

- Use figures to diagnose your results and to compare the results of the various scenarios. The easiest plotting function is Pandas' built-in plot() method. For example: vehicles_baseline['outflow'].plot() https://pandas.pydata.org/pandas-docs/stable/reference/api/pandas.DataFrame.plot.html

- To plot results from different dataframes with Pandas' plot(), you need to combine them into one dataframe. Use pd.concat() for that. It will add an extra column name (with the keys argument) for the scenario name, to differentiate the same column from each source dataframe. This is called multiindex in Pandas and it's a very useful feature. There's an example in our vehicles_baseline.py for combining the steel & aluminum results into one dataframe and then plotting only certain columns, and in the

same fashion you can use it to combine scenario results as well.
https://pandas.pydata.org/pandas-docs/stable/reference/api/pandas.concat.html
https://towardsdatascience.com/how-to-use-multiindex-in-pandas-to-level-up-your-analysis-aeac7f451fce

- To linearly interpolate values for parameters over time you can use Excel, or better yet do it in Python with np.interp(). There's a working example in week 3's extra question. And of course the internet can help too: https://numpy.org/doc/stable/reference/generated/numpy.interp.html

- In the assumptions, we related the median (14.57) to the scale and shape parameters (16.93.. and 2.42.. respectively). The relationship between the median and the Weibull's scale and shape parameters is an equation. In fact, most distribution functions have equations to calculate their means, medians, and other statistics. These equations are provided in the sidebar in Wikipedia, e.g. https://en.wikipedia.org/wiki/Weibull_distribution . This means that if we know or assume the median and at least one of the parameters, we can use the equation to calculate the other parameter to create a new survival curve. This is beyond the requirements of this course, but it's good to know.

Good luck!

References

Fishman, T., Myers, R.J., Rios, O., Graedel, T.E., 2018. Implications of Emerging Vehicle Technologies on Rare Earth Supply and Demand in the United States. Resources 7. https://doi.org/10.3390/resources7010009

Mayer, A., Haas, W., Wiedenhofer, D., Krausmann, F., Nuss, P., Blengini, G.A., 2019. Measuring Progress towards a Circular Economy: A Monitoring Framework for Economy-wide Material Loop Closing in the EU28. J. Ind. Ecol. 23, 62–76. https://doi.org/10.1111/jiec.12809

Sims, Z.C., Kesler, M.S., Henderson, H.B., Castillo, E., Fishman, T., Weiss, D., Singleton, P., Eggert, R., McCall, S.K., Rios, O., 2022. How Cerium and Lanthanum as Coproducts Promote Stable Rare Earth Production and New Alloys. J. Sustain. Metall. https://doi.org/10.1007/s40831-022-00562-4