THE HARMONEY MACROECONOMIC FRAMEWORK CONSISTENTLY ACCOUNTS FOR MONEY, ENERGY, AND MATERIAL STOCKS AND FLOWS: CALIBRATION TO THE UNITED STATES

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Overview

To effectively model the long-term dynamics and feedbacks among energy, materials and economic outcomes (e.g., gross domestic product, employment, wages, debt, etc.) economic frameworks should consistently merge the physical, energetic, and financial perspectives of the economy within a dynamic model. The Human and Resources with MONEY (HARMONEY) model is one such framework that uses an input-output structure and is stock and flow consistent in money while also tracking conservation of energy and mass along with depletion feedbacks from extraction of a natural resource (King (2020, 2022)). To date, HARMONEY is a "toy model." This paper summarizes the effort to enable the HARMONEY model to represent a real-world economy by calibrating data to the United States economy for the years 1970-2017. The U.S. economy is divided into seventeen productive sectors as well as households and the federal government. One research goal is that this calibration procedure can be applied to model other country economies.

Methods

We aggregate and allocate all energy flows within the International Energy Agency's Extended World Energy Balances data set. HARMONEY models the energy consumption, as fuel, for each type of capital, and we summarize that calibration procedure for the approximately 100 exajoules per year of primary energy (in 2017) consumption of coal, natural gas, oil, and refined oil products, and electricity including from renewable primary energy (as electricity) technologies. We calibrate mass stocks and flows using various U.S. government data and industrial ecology literature (e.g., Streeck et al., (2021)) for the following major categories of raw and processed materials (some of which are also energy resources used as material feedstocks): coal, natural gas, oil, refined oil, aggregates (sand, gravel, rocks), agricultural output (raw agriculture, food), biomass (wood and paper products), plastic, cement, iron & steel, and non-ferrous metals of aluminium and copper. The mass flows include those associated with investment as well as end-of-life (discarding and recycling) of materials in fixed capital and consumer goods.

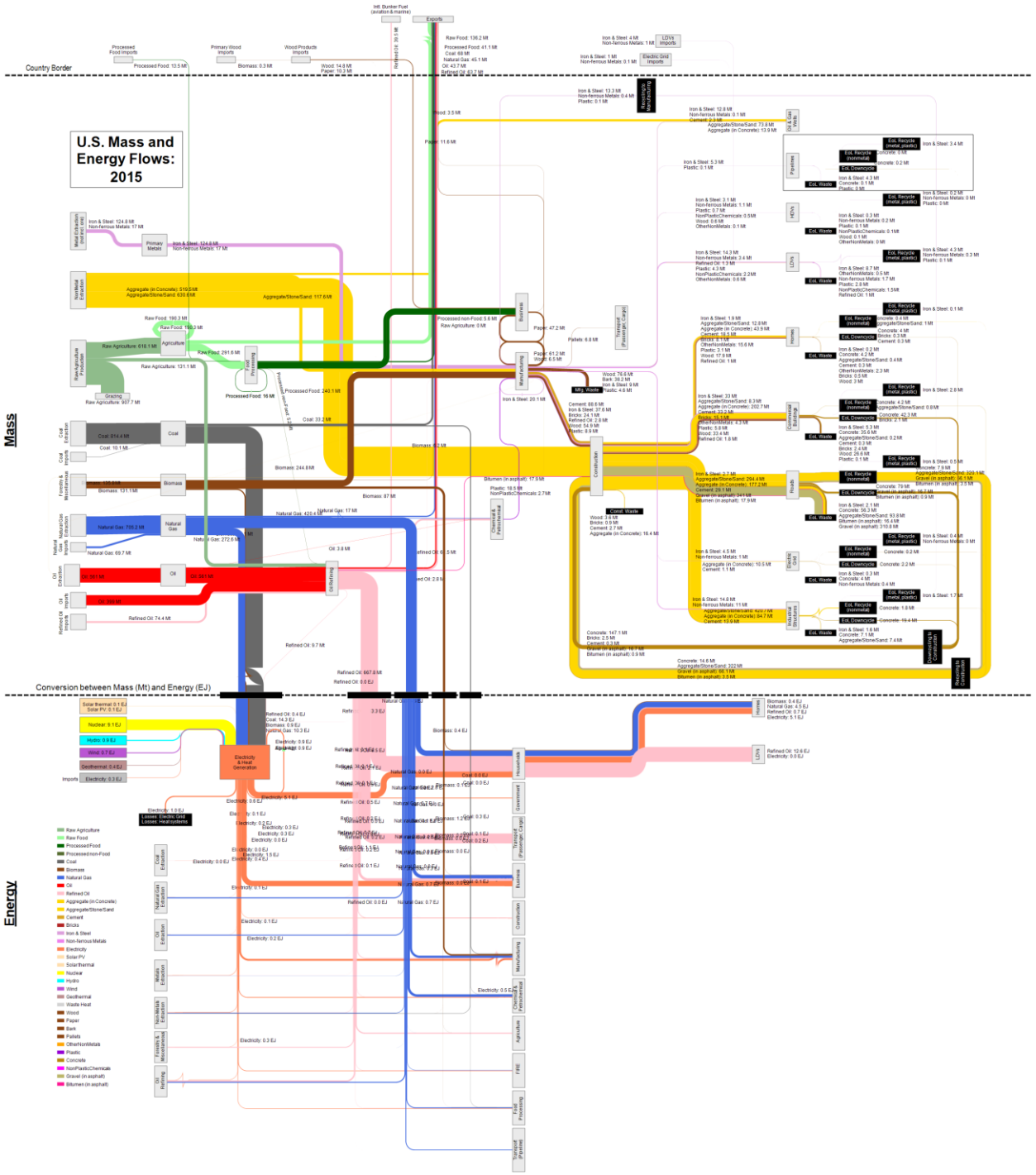
We allocate approximately 2-3 gigatonnes per year (Gt/year) of material flows and 100 gigatonnes of material stock (in 2017) among 10 categories of capital, such as roads, buildings, and vehicles. Two categories are subdivided into multiple types of capital. "Industrial" capital is subdivided into 12 for each major industry (e.g., oil extraction, construction), and "electricity" capital is subdivided into 7 types of power plants as well as transmission and distribution infrastructure.

Results

We summarize the data in two ways. First, a series of Sankey diagrams that visualize the flows of mass and energy throughout the U.S. economy (see figure for example for the year 2015). Second, a set of three matrices that can be used within an input-output macroeconomic modeling framework: (1) a capital matrix ("capital by industry") that describes the quantity of each type of capital that is owned by each economic sector, (2) an energy matrix ("industry by capital") that describes annual energy consumption of each type of energy carrier (that is output from a defined industry) by each type of capital, and (3) a materials matrix ("industry by capital") that describes the material inflows required to build each major category of capital. These data will be open-sourced except for data under proprietary constraints.

Conclusions

There are enough data and knowledge within the literature to create a macroeconomic growth model that describes all three of money, energy, and material flows within a framework that is both stock and flow consistent and characterizes all three flows within input-output tables. The next step in this research is to link the energy and material stocks and flows to the monetary data for a full calibration of the HARMONEY modelling framework to the country scale of the United States to solve for prices, costs, and other variables and parameters that enable modeling of the non-physical aspects of the economy such as wages and debt.



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