Diet and Pollution: How Agriculture Type Affects Population

Introduction:

The model that is the focus of this paper will attempt to demonstrate the relationship between diet, pollution and population dynamics; however, the model cannot even begin to represent the vast complexity that exists in the real world. For that reason, the model is a thought experiment that highlights relationships and behaviors rather than specific quantities. In *Thinking in Systems, A Primer*, Meadows emphasizes that “pretending something doesn't exist if it’s hard to quantify leads to faulty models”, highlighting that relationships are often more valuable than numbers in creating a comprehensive representation of real-world systems (2008, p.193). In this thought experiment, I pose the following question: How would the level of pollution and the population dynamics respond to changes in the proportion of animal products that individuals consume? I hypothesize that as the ratio of animal to plant-based products in the diet decreases, fewer pollution-related deaths will occur and the population the planet can sustain will increase.

This model is not the first in addressing the relationship between food, pollution and population. In fact, *The Limits to Growth* underscores that “population cannot grow without food”, the consumption of food is directly related to the consumption of resources; thus, producing pollution. The models all indicate that “pollution interferes with the growth of population and food.” Many of the projections for the future indicate that a collapse is inevitable, however, numerical changes may affect “the period of an oscillation or the rate of growth or the time of a collapse” (Meadows et al. 1972, p.89). Thus, the simulations of this model will attempt to determine the way that a population collapses in response to a behavior rather than whether or not the population will collapse.

Vegan and vegetarian diets have gained increasing attention in recent years as methods of improving health and preserving animal rights, however, one of the primary reasons for adopting such a diet may actually be environmental. Though plant-based food products also contribute pollution into the atmosphere, the energy inefficiency of producing meat requires a far greater input of fossil fuels. Industrial agriculture is one of the largest sectors of fossil use, accounting for approximately 17% of all use. Even with the most conservative estimates, the production of one kg of beef requires 7 kg of grain. The average farm in the United States consumes about 3 kcal of fossil energy in order to produce only 1 kcal of food energy; however, farms that produce meat and utilize the standard feedlot system require up to 35 kcal of fossil energy for every 1 kcal of food energy (Horrigan et al., 2002). The environmental downsides of animal agriculture do not stop at the consumption of fossil fuel energy– the process also generates significant amounts of greenhouse gases such as methane. This gas is of particular importance in the discussion of climate change due to its "high absorption ability of infrared in the radiation from the sun". The global ruminant population, most of which are used for the purpose of meat or dairy production, contribute approximately 15% of the total atmospheric methane flux (Takahashi, 2011).

Though agriculture is necessary to sustain the current global population, reducing the amount of animal products in an individual's diet would significantly decrease the production of greenhouse gases. The mean amount of dietary greenhouse gas emissions in kilograms of carbon dioxide per day were calculated to be approximately 7.19 for high meat-eaters, 5.63 for medium meat-eaters, 4.67 for low meat-eaters, 3.81 for vegetarians, and 2.89 for vegans (Scarborough et al., 2014). Additionally, a 50% reduction of anthropogenic methane emissions that would result from the reduction of meat and dairy consumption would “nearly halve the incidences of U.S. high–ozone events and lower global radiative forcing” (Fiore et al., 2002)

Pollution is connected to population dynamics both directly and indirectly. Air pollution from activities such as agriculture can contribute to a decreased air quality and pose adverse health impacts on the individuals living in such areas. The World Health Organization estimates that approximately 7 million people die each year from air pollution related conditions (Air Pollution, 2020). However, most of the deaths related to the production of pollution actually result from the adverse effects of climate change. There is almost unanimous consensus within the scientific community that anthropogenic greenhouse gas emissions are responsible for the patterns of climate change that the planet has experienced in at least the past 50 years. The environment is not the sole victim of climate change– many of the anticipated impacts of a changing climate result in human deaths. A changing climate will increase the risk of heat-related illnesses and deaths, the risk of deaths from drought and food shortages, and the risk of death from natural disasters and severe weather events (Greenhouse Gases | US EPA, 2020).

Methods:

STELLA modeling software was utilized to construct the model. Construction of the model began with the population component. The input flow to the stock of population is the number of births while the output flow of the stock is the number of deaths. A converter labeled “r” represents the birth rate and connects to the birth flow while death rate connects to the death flow. Connectors were added from the population stock to the birth and death flows to make the flows a function of the population as well. The birth and death flows were computed by multiplying the birth rate times the population and the death rate times the population respectively. This was done because the number of births and deaths is not only dependent on the rate, but the number of individuals in the population as well.

Since the goal of the model is to demonstrate the varying impacts of animal-based and plant-based food products on pollution, the stock of food was divided into the two stocks of animal food products and plant food products. Similarly, the stock of pollution was divided into that which was generated from the production of animal-based food products and that generated from plant-based food products. To account for the increase in available food products, a flow representing food production was included for both animal and plant-based food products. The stock of acres of land for food production was connected to both input flows and multiplied by either the animal-based food yield per acre converter or the plant-based food yield per acre converter to calculate the stock values. The food yield per acre in this model was set as a hypothetical "10" kCal per acre for plant-based food and only a hypothetical "1" kCal per acre for animal-based food. This is a hypothetical value, however, various studies discussed in the introduction present a similar number and the 10 % trophic level energy transfer principle supports this decision. In order to account for the feedback loop that would inevitably occur in a real-world system, the ratio of animal to plant food cost (the steps for calculating this will be discussed later in this section) converter was also connected to the animal-based food production flow. The higher the price of the food, the less likely an individual is to buy it when an alternative (plant-based foods) exist. For that reason, the ratio of animal to plant food cost was included in the denominator of the animal food production flow so that cost would be inversely related to the production.

From the stock of animal and plant-based food products is the output flow of consumption. For both flows, this mechanism was calculated by multiplying the population by the required food per person. A converter of fraction animal-based food was connected to the consumption of animal-based food products to multiply the other variables of the output flow equation. The output flow of consumption of plant-based food products was calculated similarly, however, the converter of fraction plant food was connected to the flow in order to multiply the other variables. The only two options for components of an individual's diet are plant-based foods or animal-based food; therefore, the two converters must be complements of each other and add to 1. To achieve this, the fraction animal food converter was connected to the fraction plant food converter so that the equation could be set to 1- fraction animal food.

Since the consumption of food products is directly related to the agriculture derived pollution, the output flow of consumption for both plant-based and animal-based food products was connected to the input flow of animal-based food and plant-based food pollution production, respectively. Thus, consumption equals pollution for the flows. A converter of animal to plant-based food pollution ratio was connected to the input flow for the animal-based pollution. This was to account not only for the greater quantity of particles produced in the animal agricultural process, but also the potency of the molecules in terms of climate warming potential. The absorption of pollution output flows was set to constant values of 0.8 for both pollution stocks as the rate would be equal for both.

Two converters, cost of animal and plant-based pollution, were created with connectors from both pollution stocks and an additional converter that set a cost per unit pollution rate. The cost of each type of pollution was calculated by multiplying the pollution stocks by the cost per unit pollution. The purpose of accounting for cost was to provide a feedback loop, as the price of food would impact individual's diet decisions. A ratio of animal to plant-based food cost converter with connectors from both the pollution cost converters was created and calculated by dividing the animal-based pollution-cost by the plant-based pollution cost. This converter was then connected to the animal-based food production flow that was discussed earlier.

After these components were created, the portion of the model which accounted for how pollution impacted population was constructed. The death rate converter, used to calculate the deaths output flow for the pollution stock, was connected to the converters of base death rate, required food per person, food per person and mortality rate due to pollution. To calculate the mortality rate due to pollution, the converters of total pollution and pollution tolerance were connected to the converter and the rate was calculated by dividing total pollution (simply a summing converter of both pollution stocks) by pollution tolerance so that the mortality rate increases as total pollution increases and decreases as pollution tolerance increases. To account for mortality due to lack of food, the required food per person was divided by food per person; thus, as the amount of food decreased or the individual food requirements increased, the death rate would also decrease. The base death rate, mortality rate due to lack of food and mortality rate due to pollution were then summed to calculate the overall death rate.

To answer my question for this experiment, the fraction of animal-based food in an individual's diet was set to 5 different values to determine how the pollution and population stocks would respond. Though many of the converters could be adjusted to answer different questions, the primary focus of this experiment was to analyze the response to a changing diet. The values entered into the stocks were relatively low considering the actual values in a real-world system, however, given that the model is very complex and is only intended as a thought experiment, these numbers were sufficient in modeling the system behavior. The population stock was set to 250 people, both food product stocks set to 1000 kcal and both pollution stocks set to 1000 kg of pollution. Ultimately the impact of a changing fraction of animal-based food was analyzed by determining both the peak population number and the peak pollution number. Additionally, the shape of the population curve will be described to indicate how the population collapses.

Results:

The completed model is shown below: (a larger version is included after the references)

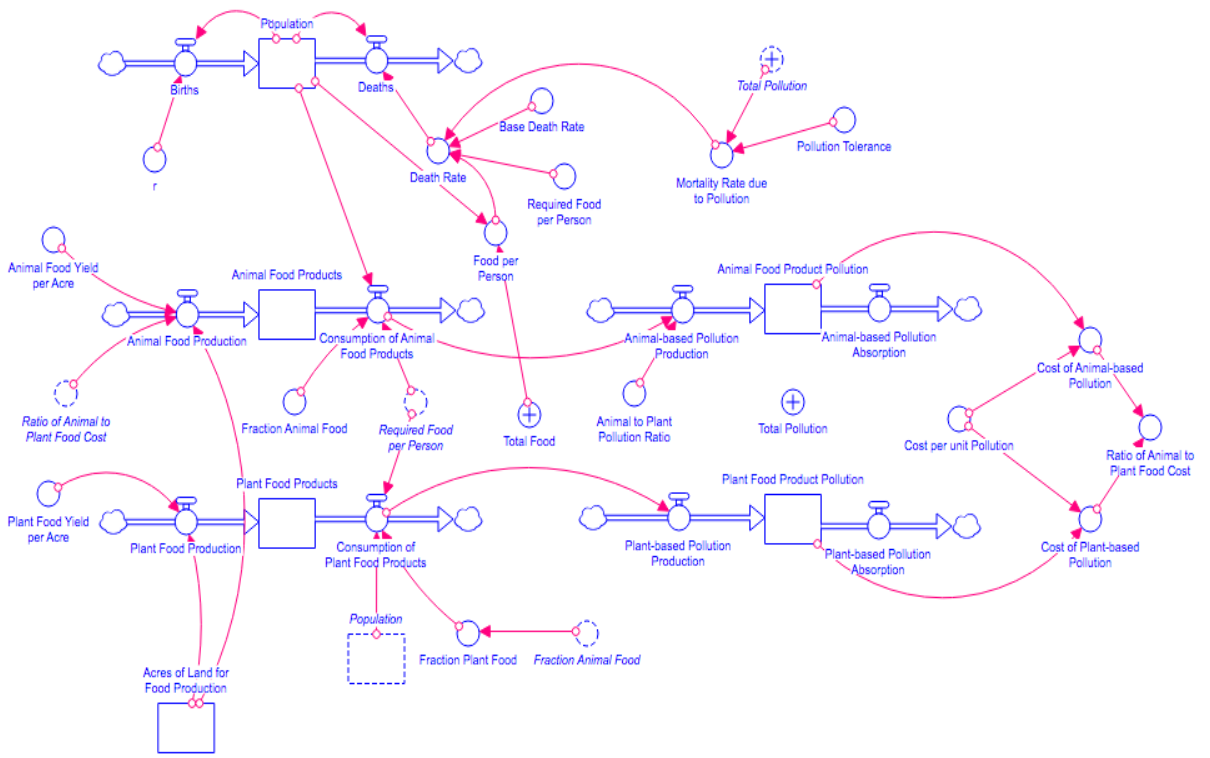


Figure 1. Completed Model

The simulations in this thought experiment indicate that when individuals consume less animal products in their diet, a larger population can be sustained, and the collapse isn't as severe. This result is directly related to the decreased level of pollution when individuals adopt a more plant-based diet

When the proportion of animal-based food products in the diet is adjusted to 1.00 or 100%, the maximum level of pollution was determined to be 41,000 k kg of pollution and the maximum population that can be sustained was determined to be 330 people. In this simulation, the population begins to collapse after year 6 and only takes around 25 years for the population to be nearly eradicated.

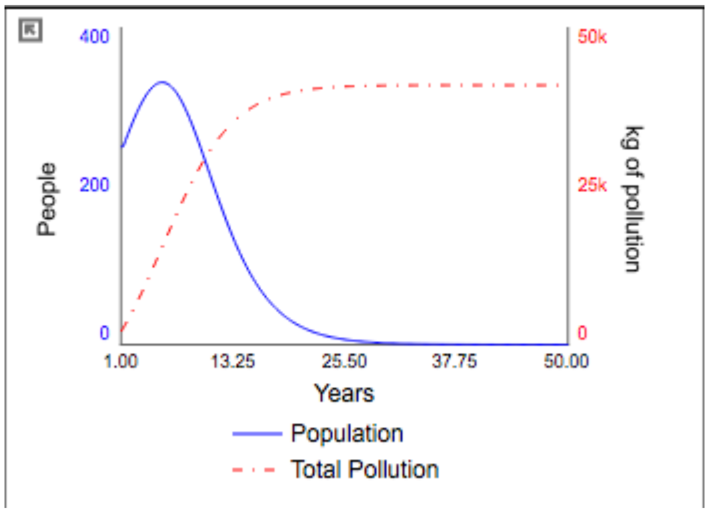


Figure 2. Pollution and Population at 100% Animal-based Products in Diet

When the proportion of animal-based food products in the diet is adjusted to 0.75 or 75%, the maximum level of pollution was determined to be 38.7 k kg of pollution and the maximum population that can be sustained was determined to be 355 people. In this simulation, the population begins to collapse after year 7 and only takes around 30 years for the population to be nearly eradicated.

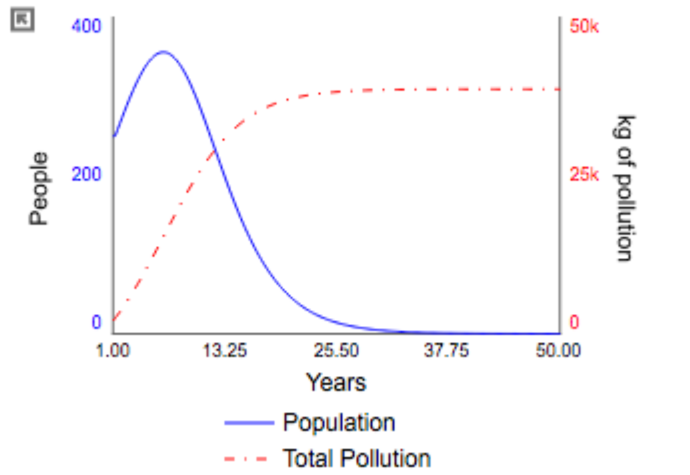


Figure 3. Pollution and Population at 75% Animal-based Products in Diet

When the proportion of animal-based food products in the diet is adjusted to 0.5 or 50%, the maximum level of pollution was determined to be 36.1 k kg of pollution and the maximum population that can be sustained was determined to be 401 people. In this simulation, the population begins to collapse after year 8 and only takes around 35 years for the population to be nearly eradicated.

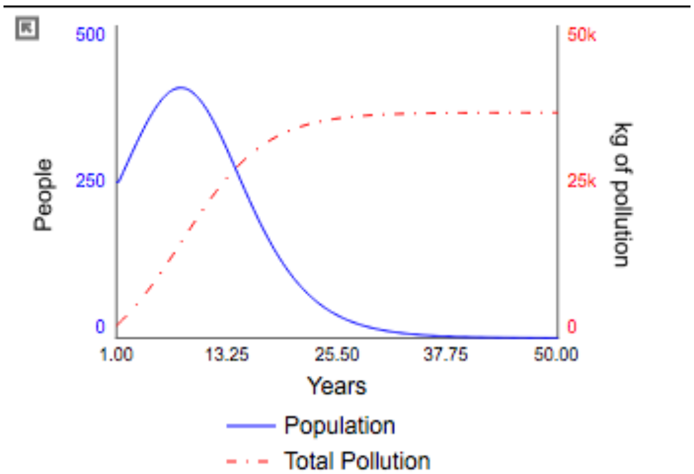


Figure 4. Pollution and Population at 50% Animal-based Products in Diet

When the proportion of animal-based food products in the diet is adjusted to 0.25 or 35%, the maximum level of pollution was determined to be 33.2 k kg of pollution and the maximum population that can be sustained was determined to be 509 people. In this simulation, the population begins to collapse after year 11 and only takes around 40 years for the population to be nearly eradicated.

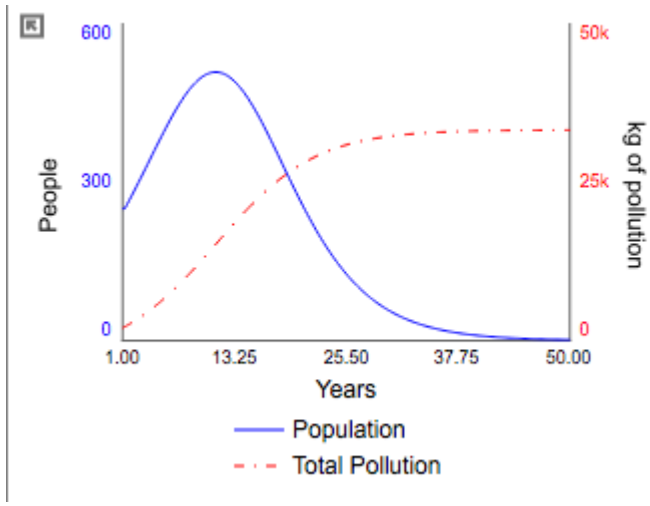


Figure 5. Pollution and Population at 25% Animal-based Products in Diet

When the proportion of animal-based food products in the diet is adjusted to 0.00 or 0%, the maximum level of pollution was determined to be 29.6 k kg of pollution and the maximum population that can be sustained was determined to be 1.1 k people. In this simulation, the population begins to collapse after year 21 and takes over 50 years for the population to be nearly eradicated.

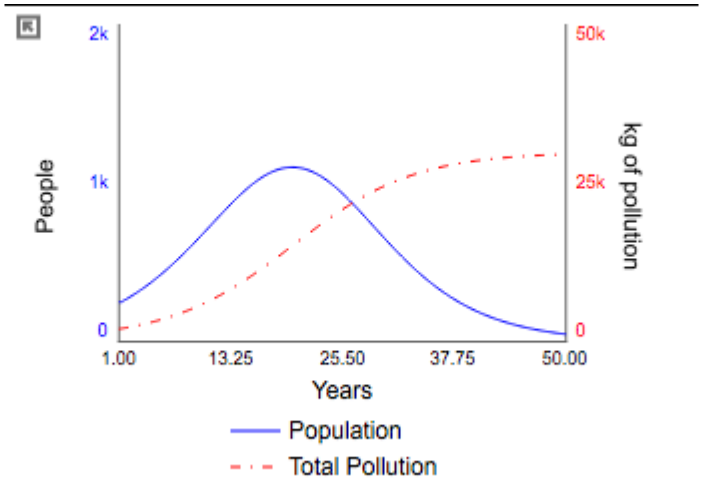


Figure 6. Pollution and Population at 0% Animal-based Products in Diet

These results indicate that as the proportional of animal-based products decreases in the diet, the amount of pollution produced will decrease. As this pollution decreases, the population that can be sustained before the collapse will increase exponentially, the amount of time that the population can be sustained before a collapse will increase, and the number of years before the population is entirely eradicated will increase as well.

Discussion:

The results of these model simulations demonstrate a clear relationship between the type of food in one's diet, pollution produced, and population that can be sustained; however, there are several limitations to the model and challenges with constructing it that may affect the validity of these conclusions. After all, "we live in a world in which everything is knotted together" and systems are "an impregnable tangle of causes and effects". Though each individual component of the model was thought out carefully and researched, "even when a system is dissected into its basic parts" there are still "forces we can't understand or haven't considered or don't think matter (Lehrer et al., 2020). A model that captures the complexity of a real-world system is impossible to construct; thus, the results of this thought experiment can in no way be accepted as factual. Additionally, the values that were used in the model were chosen for simplicity in understanding the behaviors of the model rather than generating numerically accurate predictions.

With the information presented in the introduction in addition to the model simulations, it is reasonable to conclude that one of the solutions to either preventing a collapse or lessening the severity of a collapse may be to transition to a more plant-based diet. In fact, a single half-pound burger requires the same amount of grain that could "meet the entire total daily energy and protein needs of three people in India" if those individuals were to consume a combined grain and milk diet (Baus, 2017). The increased energy efficiency of eating a diet that is more plant-based is widely established, however, the feasibility of the current world population transitioning to such a diet is not as well understood.

The feedback loop included within the model essentially represents the internalization of an externality. The externality in this particular thought experiment would be the production of pollution. Since "any balancing feedback loop needs a … response mechanism", creating a leverage point within this system would require some structure to enforce this feedback loop (Meadows 2008, 169). A carbon tax is a fairly well-known method of internalizing an externality in which the external cost of greenhouse gas production is factored into the price of fossil fuel-based energy sources. This would encourage individuals to invest in renewable energy sources that do not include this tax. After nations such as Britain have implemented a carbon tax, "coal use plummeted" (Plumer and Popovich, 2020). This model proposes that if a mechanism such as a pollution tax was introduced, the polluting power of animal-based foods would be reflected in their price and individuals would adopt a more plant-based diet.

Previous civilizations and the many of the current projections for the world's population patterns suggest that a collapse is inevitable. However, maximizing the current carrying capacity of the planet and delaying a collapse as well as reducing the severity of a collapse is of utmost importance to the civilizations of the world today.

References Cited

2020. *Air Pollution*. [online] Available at: <https://www.who.int/westernpacific/health-topics/air-pollution> [Accessed 5 May 2020].

Baus, D., 2017. Overpopulation and the Impact on the Environment.

Fiore, A.M., Jacob, D.J., Field, B.D., Streets, D.G., Fernandes, S.D. and Jang, C., 2002. Linking ozone pollution and climate change: The case for controlling methane. *Geophysical Research Letters*, *29*(19), pp.25-1.

Horrigan, L., Lawrence, R.S. and Walker, P., 2002. How sustainable agriculture can address the environmental and human health harms of industrial agriculture. *Environmental health perspectives*, *110*(5), pp.445-456.

Lehrer, J., Lehrer, J., Strampe, L., Staff, W., Cohen, N., Watercutter, A., Greenberg, A. and Barrett, B., 2020. *Trials And Errors: Why Science Is Failing Us*. [online] WIRED. Available at: <https://www.wired.com/2011/12/ff-causation/> [Accessed 4 May 2020].

Meadows, D.H., 2008. Thinking in systems: A primer. Chelsea Green Publishing.

Meadows, D.H., Meadows, D.L., Randers, J. and Behrens, W.W., 1972. The limits to growth. New York.

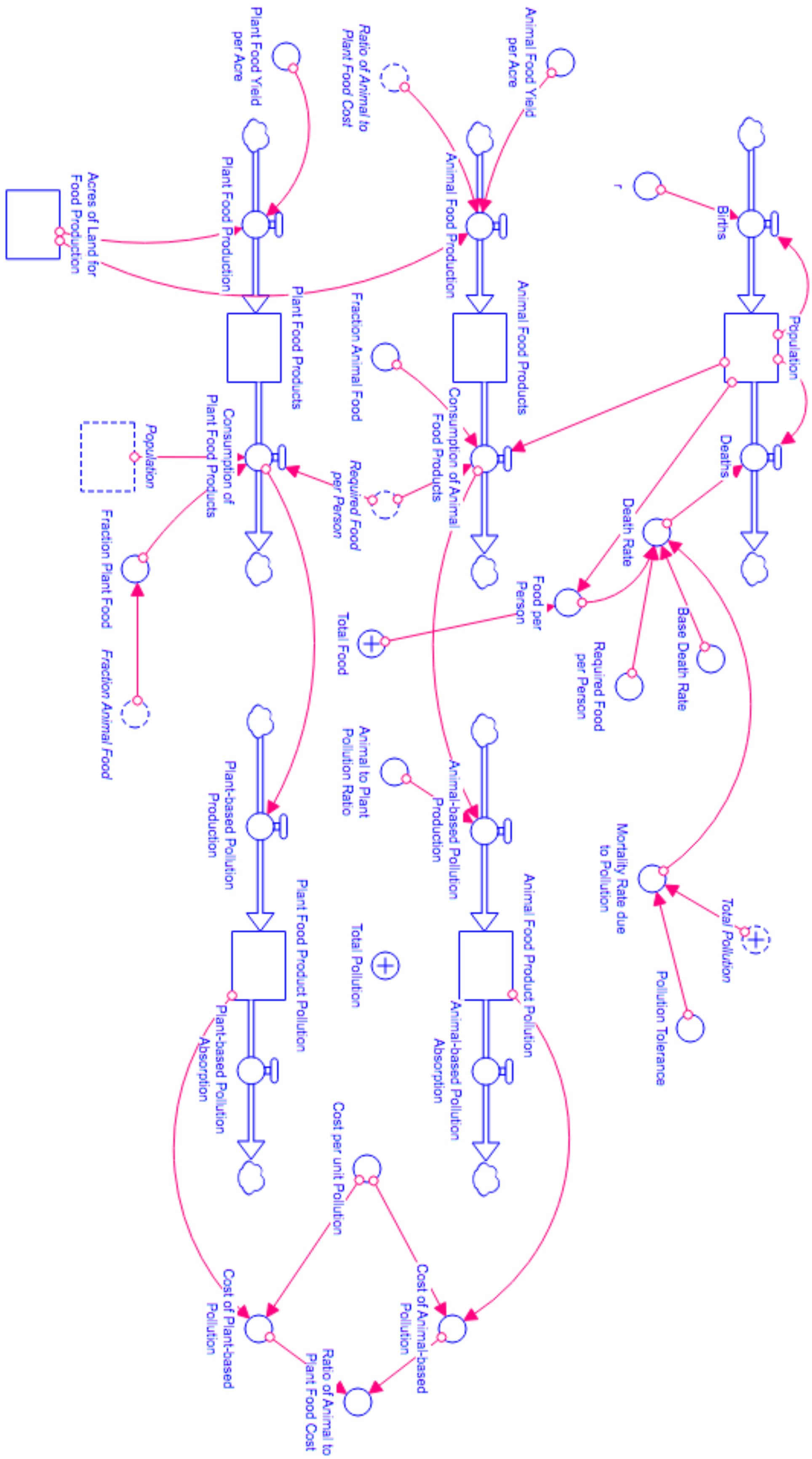
Plumer, B. and Popovich, N., 2020. *These Countries Have Prices On Carbon. Are They Working?*. [online] Available at: <https://www.nytimes.com/interactive/2019/04/02/climate/pricing-carbon-emissions.html> [Accessed 5 May 2020].

Report on the Environment. 2020. *Greenhouse Gases | US EPA*. [online] Available at: <https://www.epa.gov/report-environment/greenhouse-gases> [Accessed 5 May 2020].

Scarborough, P., Appleby, P.N., Mizdrak, A., Briggs, A.D., Travis, R.C., Bradbury, K.E.

and Key, T.J., 2014. Dietary greenhouse gas emissions of meat-eaters, fish-eaters, vegetarians and vegans in the UK. *Climatic change*, *125*(2), pp.179-192.

Takahashi, J., 2011. Some Prophylactic Options to Mitigate Methane Emi ssion from Animal Agriculture in Japan. *Asian-Australasian Journal of Animal Sciences*, *24*(2), pp.285-294.


Births
r
Population
Deaths
Death Rate
Food per Person
Base Death Rate
Required Food per Person
Total Food
Mortality Rate due to Pollution
Total Pollution
Pollution Tolerance
Animal Food Yield per Acre
Ratio of Animal to Plant Food Cost
Animal Food Production
Animal Food Products
Fraction Animal Food
Consumption of Animal Food Products
Plant Food Yield per Acre
Plant Food Production
Acres of Land for Food Production
Plant Food Products
Required Food per Person
Consumption of Plant Food Products
Population
Fraction Plant Food
Fraction Animal Food
Animal to Plant Pollution Ratio
Animal-based Pollution Production
Animal Food Product Pollution
Animal-based Pollution Absorption
Total Pollution
Plant-based Pollution Production
Plant Food Product Pollution
Plant-based Pollution Absorption
Cost per unit Pollution
Cost of Animal-based Pollution
Cost of Plant-based Pollution
Ratio of Animal to Plant Food Cost