Questions?
A cause and effect graph

- UVB absorbs ozone
- Ozone destroys CFCs
- CFCs cause cancer
- Cancer causes UVB
"smoking gun" against CFCs

Inverse correlation between ozone and CFC biproduct ClO.

The connection between CFCs and ozone depletion

Ozone

CFC

ClO

Cl•

O_3

O_2

sunlight

ice crystals

equator south pole latitude

LtG p.191
rise and fall of CFCs

LtG p.183
What would have happened?

Forward projections given policy scenarios.

1974  First public awareness.
1992  Copenhagen Amendments.
The ozone hole in the southern hemisphere from 1979

2000  2001  2002  2003  2004  2005  2006
2007  2008  2009  2010

https://youtu.be/Gjjv5IiyzVM

http://www.theguardian.com/
How did they do it?

- Long-term thinking.
- Good data, good model.
- International cooperation.
- Frequent monitoring.
- Revision, maintenance.
Can we do it again?

- **Climate change**
  - Global agreement reached 2015!
  - Tech solutions reaching mass market!
  - Recent set-backs.

- **Overpopulation**
  - Still in early stages. Many books. Some activist groups. No global discussion. No funding for research!
  - Beginnings of recognition that family planning and ecological conservation are directly linked.

www.devex.com/news/family-planning-takes-a-360-degree-approach-87892
Purpose of the World models

• "broad sweep of the future"

• "to avoid creating an impenetrable thicket of assumptions, modelers must discipline themselves. They cannot put into the model all that they know, only what is relevant for the purposes of the model." (LtG)
Figure 3.1: Complete diagram of the world model interrelating the five-level variables — population, natural resources, capital investment, capital investment-in-agriculture fraction, and pollution.
population is one stock
birth, death have multipliers.

Open system:
clouds indicate
outside source and sink.

Single demographic
Exponential growth rates with "multipliers"

Multipliers: Food, Pollution, Materials, Crowding
natural resources do not regenerate, include non-renewables.

Open system: One source, one external sink.

All natural resources (renewable and non-renewable, material and energy) modeled as a single stock.

Usage rate is determined by population and "Material standard of living", which also determines "quality of life".
Pollution affects quality of life and life expectancy.

Open system: external sources and sink. No units.

Pollution absorption is exponential (see feedback loop).

Pollution generation inputs from population and capital investment (affluence?).

Pollution outputs to death rate, Quality of Life (QOL). QOL has no outputs. Just an index.
How is land modeled in World 1?

Variable, not stock: capital investment in agriculture.

Input variables are Food, Quality of life from food, quality of life from Materials.

Output to Food Potential, which becomes Food per capita, which inputs to birth and death rates.
How is **energy** modeled in World 1?

**Capital investment (CI) stock: open system**

Input to CI from population and **Material Standard of Living**.

Output to **agriculture**, **material standard of living**, and **pollution**.

**NOTE**: I call this energy.
1972 World model

- Non-renewables are separate from natural resources.
- Population is broken up into age demographics.
- Adds service capital, labor force.
- Land is modeled as two open systems of stocks: 1) land (potential, arable, degraded) and 2) land fertility.
Population is broken up into age demographics. This allows us to ask, "how does this scenario affect the age distribution?"
So, it makes for a more useful model, but is it at the expense of a bigger, more complex model...?
Nonrenewables are modeled as a stock with only an out-flow, not in-flow.

Persistent pollution is modeled as one stock with one half-life of assimilation.
Economics is modeled as two stocks: service capital and industrial capital. Input flows are "investments", output flows are "depreciation."
Agriculture is modeled as three types of land with one-way transitions. No cycle back from urban to arable, nor from arable to potentially arable (i.e. wild).
"World 2" model -- Jay Forrester

- Similar to World 1 (1971 version)
  - Open systems for population, natural resources, capital investment (physical capital), capital investment in agriculture, pollution.
  - Central variable in Material Standard of Living (MSL)
  - Single demographic
  - Non-renewable resources are not explicitly modeled

An important assumption that was made is that as the nonrenewable resources are extracted, the remaining resources are increasingly difficult to extract, thus diverting more and more industrial output to resource extraction.
More work needs to be done on modeling

From the author of LtG

Donella Meadows in "Groping in the Dark: The First Decade of Global Modelling"

"We have great confidence in the basic qualitative assumptions and conclusions about the instability of the current global socioeconomic system and the general kinds of changes that will and will not lead to stability. We have relatively great confidence in the feedback-loop structure of the model, with some exceptions which I list below. We have a mixed degree of confidence in the numerical parameters of the model; some are well-known physical or biological constants that are unlikely to change, some are statistically derived social indices quite likely to change, and some are pure guesses that are perhaps only of the right order of magnitude. The structural assumptions in World3 that I consider most dubious and also sensitive enough to be of concern are:

• the constant capital-output ratio (which assumes no diminishing returns to capital),
• the residual nature of the investment function,
• the generally ineffective labour contribution to output."
Over the last two centuries, the impact of the Human System has grown dramatically, becoming strongly dominant within the Earth System in many different ways. Consumption, inequality, and population have increased extremely fast, especially since about 1950, threatening to overwhelm the many critical functions and ecosystems of the Earth System. Changes in the Earth System, in turn, have important feedback effects on the Human System, with costly and potentially serious consequences. However, current models do not incorporate these critical feedbacks. We argue that in order to understand the dynamics of either system, Earth System Models must be coupled with Human System Models through bidirectional couplings representing the positive, negative, and delayed feedbacks that exist in the real systems. In particular, key Human System variables, such as demographics, inequality, economic growth, and migration, are not coupled with the Earth System but are instead driven by exogenous estimates, such as UN population projections. This makes current models likely to miss important feedbacks in the real Earth-Human system, especially those that may result in unexpected or counterintuitive outcomes, and thus requiring different policy interventions from current models. The importance and imminence of sustainability challenges, the dominant role of the Human System in the Earth System, and the essential roles the Earth System plays for the Human System, all call for collaboration of natural scientists, social scientists, and engineers in multidisciplinary research and modeling to develop coupled Earth-Human system models for devising effective science-based policies and measures to benefit current and future generations.
The Past: “Empty World”
When the Human System was small relative to the Earth System, the two could be modeled separately.

The Present: “Full World”
The Human System has grown so large that both must now be modeled coupled to each other.

Bidirectional coupling between the Earth and human systems is essential for modeling sustainability


Figure Legend:
World population and atmospheric concentrations of major greenhouse gases since the beginning of the Agricultural Revolution about 10,000 years ago until the present (left), with a magnified timescale for the period after the beginning of the Industrial Revolution (right). Code, data, data sources, calculation of the rates of change and additional configurations of the figure are available at https://dx.doi.org/10.6084/m9.figshare.4029369.
In World 3

What is overmodeled?
demographics, economics

What is undermodeled?
cycles, feedback
"You have noticed that everything an Indian does in a **circle**, and that is because the Power of the World always works in circles, and everything **tries to be round**.

In the old days all our power came to us from the **sacred hoop** of the nation and so long as the hoop was unbroken the people flourished. The flowering tree was the living center of the hoop, and the circle of the four quarters nourished it.

Everything the power of the world does is done in a circle. The sky is round and I have heard that the earth is round like a ball and so are all the stars. The wind, in its greatest power, whirls.

Birds make their nests in circles, for theirs is the same religion as ours. The sun comes forth and goes down again in a circle. The moon does the same and both are round. Even the seasons form a great circle in their changing and always come back again to where they were.

The **life of a man is a circle** from childhood to childhood, and so it is in everything where power moves."

**Black Elk, Holy Man of the Oglala Sioux** 1863-1950
Cycles: Positive feedback loops

- CO$_2$
- Climate change
- Food supply
- Deforestation
- Violence
- Starvation
- Lizard-brained-ness
- Science
- Ice
- Albedo effect
- Sea level

We do have control

We don't have control
Cycles: Negative feedback loops

- Climate change
- CO₂
- Forest
- CO₂ use
- Energy cost
- Renewable energy
- Fuel per capita
- Population
- Birth rate
- Food per capita
- Death rate
- Violence
A **circular economy** is an **economic system** that takes the reusability of products and materials and the conservation of natural resources as starting point. It also strives for value creation for people, nature and the economy in each part of the system. Ideally, making **materials circulate infinitely** makes an economy circular. This means that the **economic system functions through ecological principles**, whereby:

- All resources can be used in other parts of the economic system in a sustainable way (clean, safe, social) and all waste is used as resource
- **Renewable resources** and the usage of present-day physical processes in a smart way will become the basis of the economy
- The mining of biological and geological resources is done in a **sustainable** manner
- **Renewable energy** is used
- **New types** of organisations and business modes arise to make this possible.
What are the cycles of circularity?
In the technical aspect of the circular economy, there are five cycles of circularity. The **tightest cycle** has the highest **value**; the least tight cycle has the lowest value.
1. Product **maintenance**
2. Product **reuse / redistribution**
3. Product **refurbishment / remanufacture**
4. Product **recycling**
5. **Reprocessing** of technical nutrients

What are the principles behind a circular economy?
A circular economy is built on five principles. Also, system thinking is of high importance when considering a circular economy.
1. Design out waste
2. Build resilience through diversity
3. Rely on energy from renewable sources
4. Think in systems
5. Waste is food

Ellen MacArthur (2013), Towards the Circular Economy 1, p.24
IMSA, Unleashing the power of the Circular Economy, p.16,45
Meadows (1999), Leverage points: places to intervene in a system
Linear economy with feedback loops is the transition state between a completely linear economy and a completely circular economy.

In our current linear economic model, many elements can already be made partially circular. Think of reduced resource extraction, of increased recycling, of changing business models from product to service, of increased cooperation in the production chain and of different financing methods. Although many feedback loops can be implemented relatively easy, a complete circular economy is not yet within reach.

Ellen MacArthur (2013), Towards the Circular Economy 1, p.24
Gini coefficient

- Measure of inequality in a dataset.
- Invented to describe income inequality.
- Area over Lorenz curve and under the diagonal.
- $0 \leq G \leq 1$
- $G=0$ represents perfect equality
- $G=1$ represents a perfect inequality.

$$G = 1 - 2 \int_0^1 L(X) \, dX$$
Lorenze curve for world income, by whole countries

World Bank data, PPP 2012

Countries: Gini=0.48 (N=131)
Chart 1

Converging fortunes

Latin America is the region with the highest inequality in the world, but one of only two—along with south Asia—where inequality is falling.

(average Gini coefficient by region and income level, five-year averages)

Sources: Author’s calculations based on OECD Income Distribution Database: Gini, Poverty, Income, Methods and Concepts; World Bank, PovcalNet: An Online Poverty Analysis Tool; and CEDLAS and World Bank, Socioeconomic Database for Latin America and the Caribbean.

Note: Regional averages were calculated as the averages of within-country inequality for the countries for which data were available; thus, country coverage varies markedly by region.
Modeling Inequality

- How is Gini directly related to: (if at all)?

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