System dynamics modelling for sustainable production and consumption

Agricultural fertilizer use

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Though this be madness, yet there is method in it.

(William Shakespeare)
Sustainability and System Dynamics

A Global Forecast for the Next Forty Years

Jorgen Randers

State of the World

1900 2000 2100

Resources, Industrial output, Population, Food, Pollution
System Dynamics

\[ \frac{dP}{P} = f \cdot dt \]
\[ \int \frac{dP}{P} = \int f \cdot dt \]
\[ \ln(P) = f \cdot t + c \]
\[ P(t) = P(0) \cdot e^{ft} \]
System Dynamics

![Diagram showing population dynamics with feedback loops for birth rate, population, death rate, and carrying capacity.](image)

Population Growth

- Birth rate +
- Death rate -
- Population growth +
- Population decline -

Carrying Capacity

- Population relative to capacity +
- Mortality -
- Fertility +

Graph showing population over time with different scenarios.
System dynamics

• Top-down
• Descriptive (causal relations)
• Continuous
• Feedback-rich and nonlinear
Nitrogen Cycle

The Nitrogen Cycle

Nitrogen gas in atmosphere ($N_2$)

- Terrestrial food webs
  - Denitrification by bacteria
  - Nitrification by bacteria to $NO_3^-$
  - Nitrification by bacteria to $NO_2^-$
  - Ammonification by bacteria and fungi to $NH_4^+$
  - Nitrogen fixation by bacteria

- Freshwater
  - Nitrogenous wastes in soil

- Marine food webs
  - Nitrification by bacteria to $NO_3^-$, $NO_2^-$

- Oceans
  - Runoff
  - Fertilizers
  - Denitrification by bacteria to $N_2$
  - Nitrogenous sediments fall to ocean floor

Source: Khan Academy
FeliX Model
FeliX Model: Fertilizer Use

- Population
- Food demand
- Land requirement
- Crop yield
- Fertilizer use
- Food supply
- Agricultural land
- Deforestation
- Land discrepancy
FeliX Model: Fertilizer Use
FeliX Model: Fertilizer Use

Average Daily Calories per Capita

Total nitrogen consumption for agriculture

Cropland Yield

Agricultural and Forest Land

Average Daily Calorie Supply per Capita: BAU
Average Daily Calorie Supply per Capita: Historical Data

Total nitrogen consumption for agriculture: BAU
Total nitrogen consumption for agriculture: Historical Data

Cropland Yield: BAU
Cropland Yield: Historical Data

Agricultural Land: BAU
Forest Land: BAU
FeliX Model

Forest Protection Scenario

Forest Land

Agricultural Land

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FeliX Model
Forest Protection Scenario

Total nitrogen consumption for agriculture

Average Daily Calorie Supply per Capita
Conclusions

• System dynamics
  • to capture the core mechanisms behind sustainability challenges
  • to explore the future dynamics
  • to test our assumptions and policy interventions