

The Limits to Growth: Sustainability and the Circular Economy

Lecture 4: Limits to Growth and Planetary Boundaries

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INTRODUCTION

Introduction

Finite Systems - Sandbox / Playground



Introduction

Earth Overshoot Day

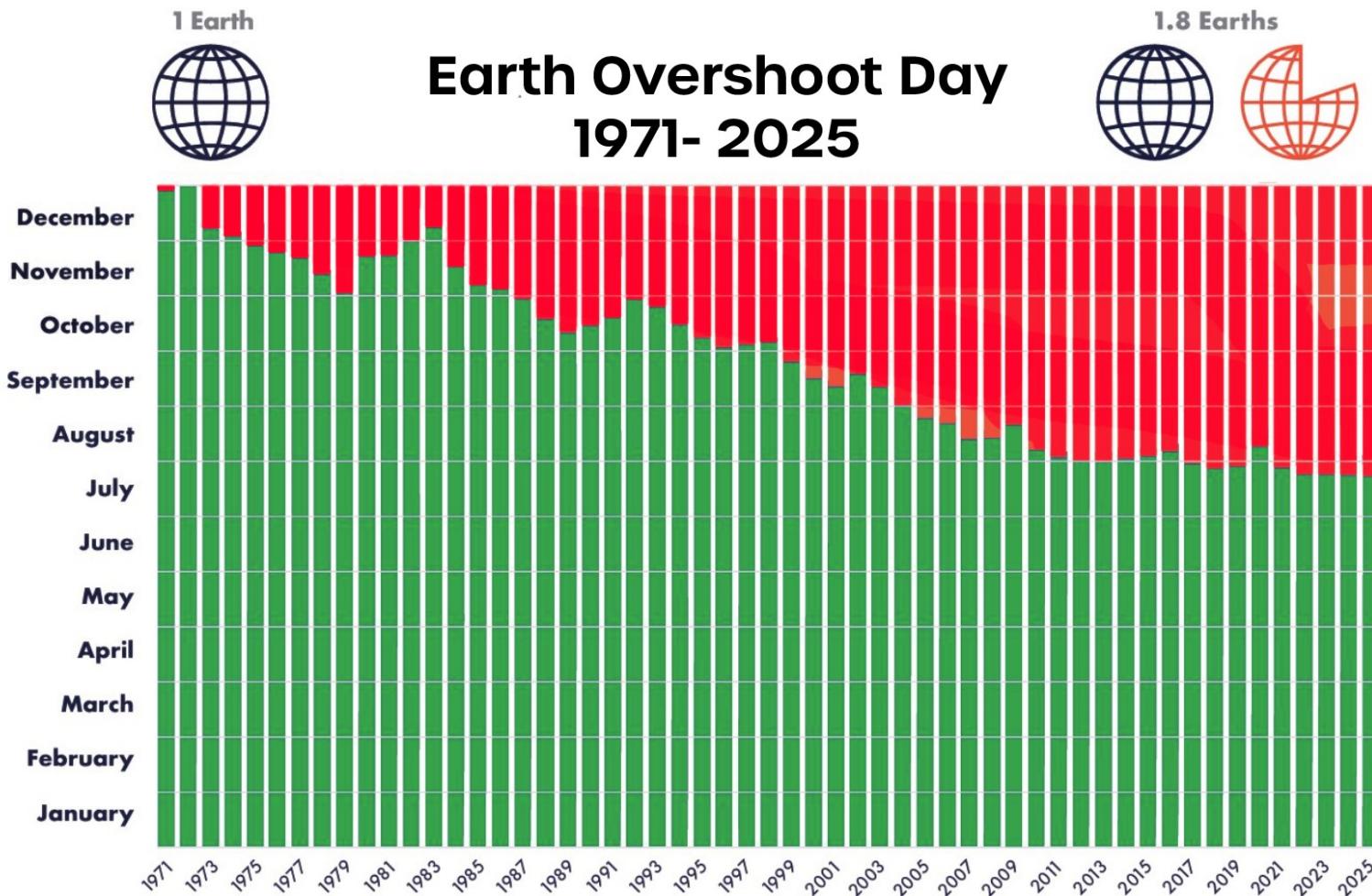


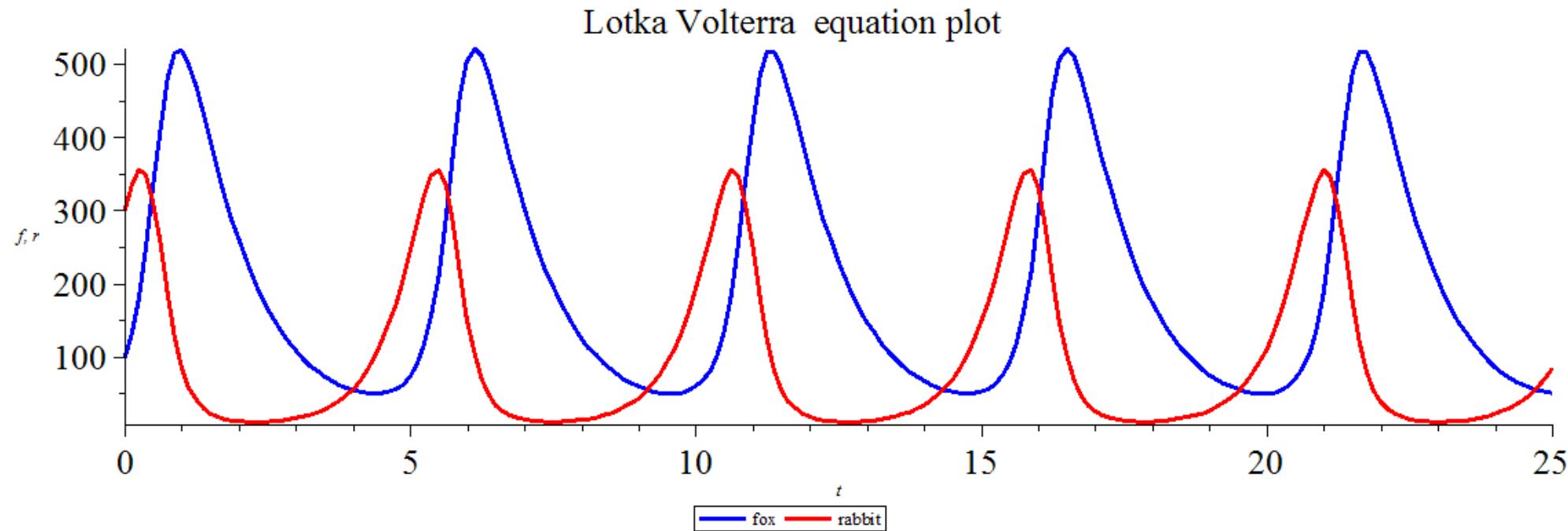
Figure adapted from <https://www.overshootday.org/newsroom/past-earth-overshoot-days/>

Introduction

Lotka-Volterra Equations (Predator-Prey Equations)

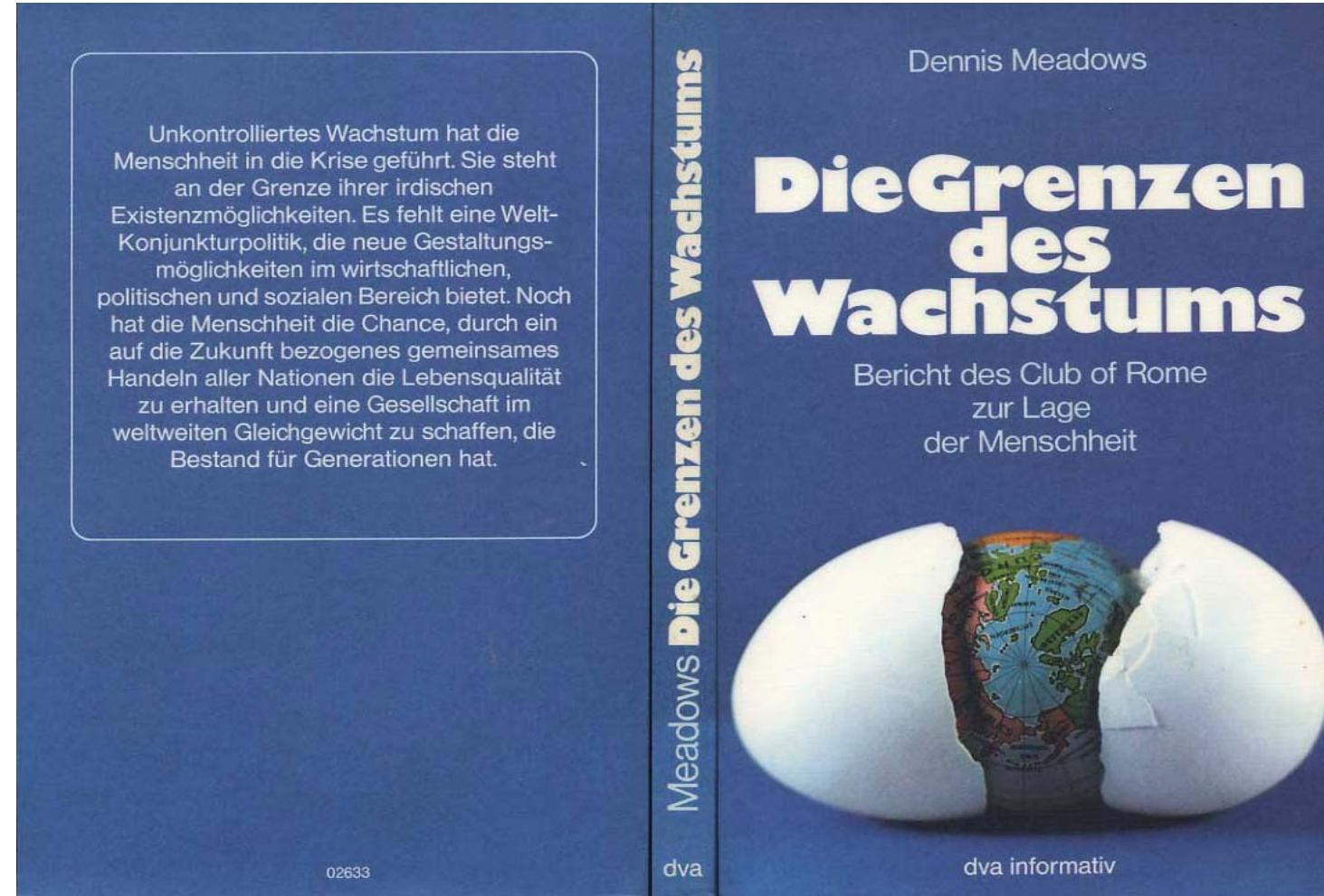
Introduction

Lotka-Volterra Equations (Predator-Prey Equations)



Introduction

The Limits to Growth - 1972



Introduction

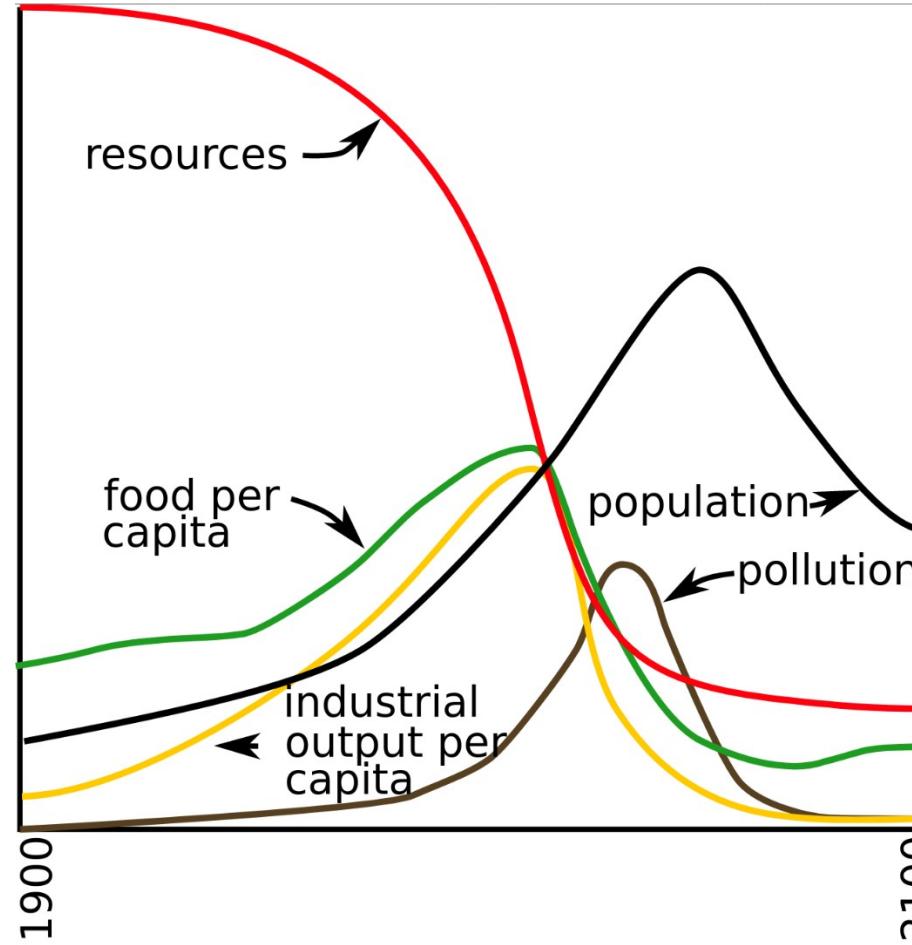
The Limits to Growth

*"If the present growth trends in world population, industrialization, pollution, food production, and resource depletion continue unchanged, **the limits to growth on this planet will be reached sometime within the next one hundred years.***

*The most probable result will be a rather **sudden and uncontrollable decline in both population and industrial capacity.***

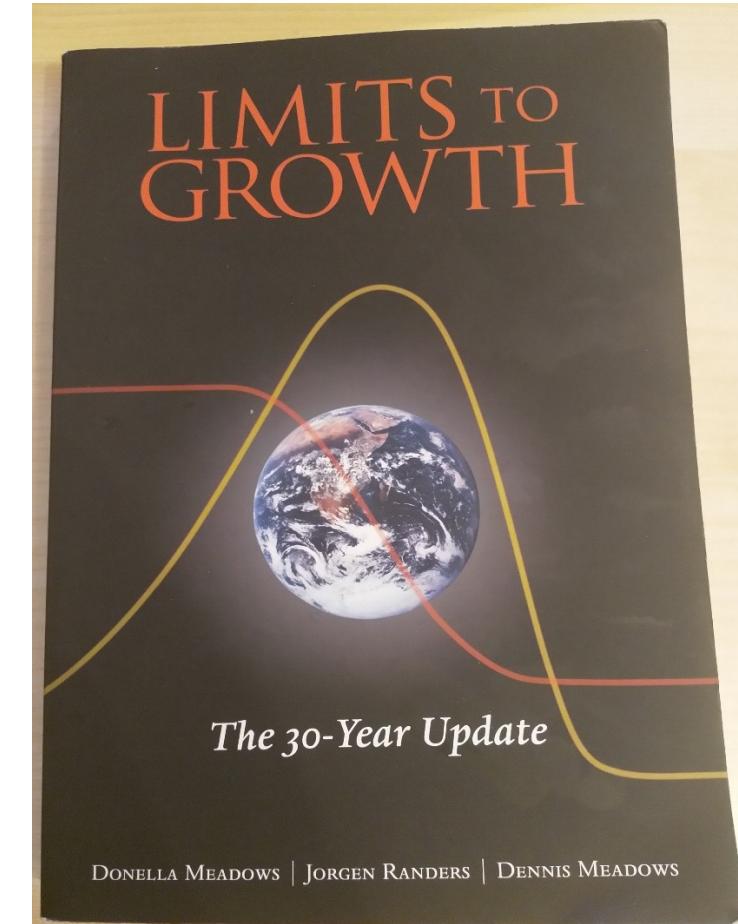
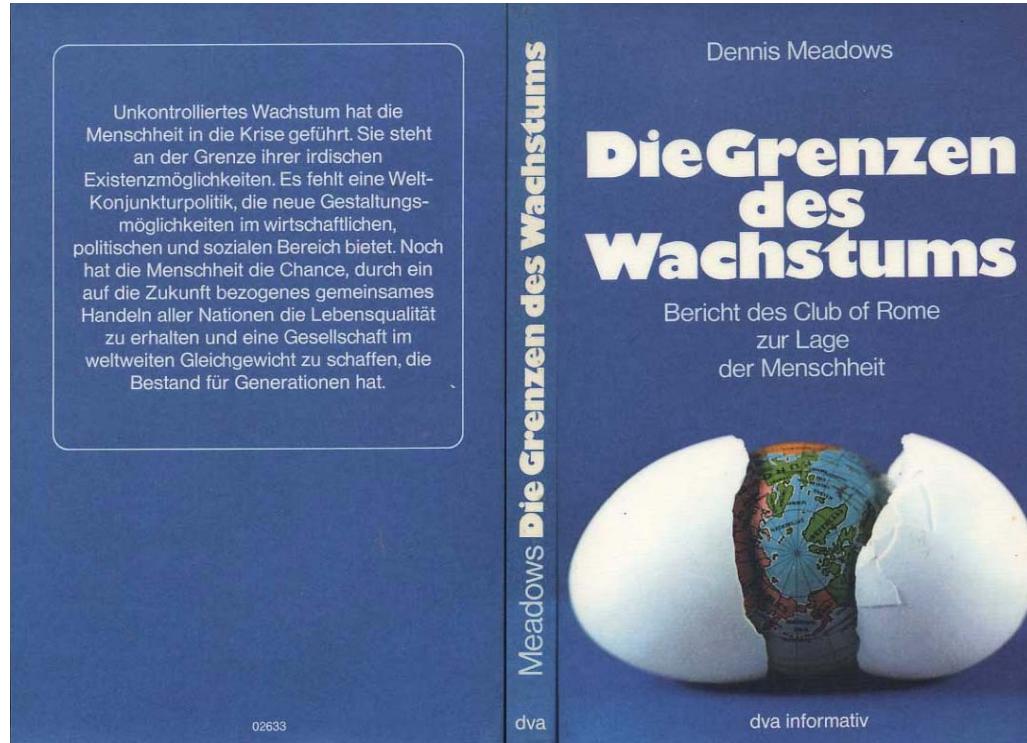
Introduction

The Limits to Growth - World3 Standard Run



Introduction

The Limits to Growth - 1972 / 2004



Introduction

The Limits to Growth - World3 Model

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PLANETARY BOUNDARIES

Planetary Boundaries

Concept

- First proposed by researchers led by Johan Rockström from the Stockholm Resilience Centre in 2009
- Quantitative planetary boundaries within which future generations can continue to exist
 - Based on nine indicators that are of high importance for the stability and resilience of the Earth system

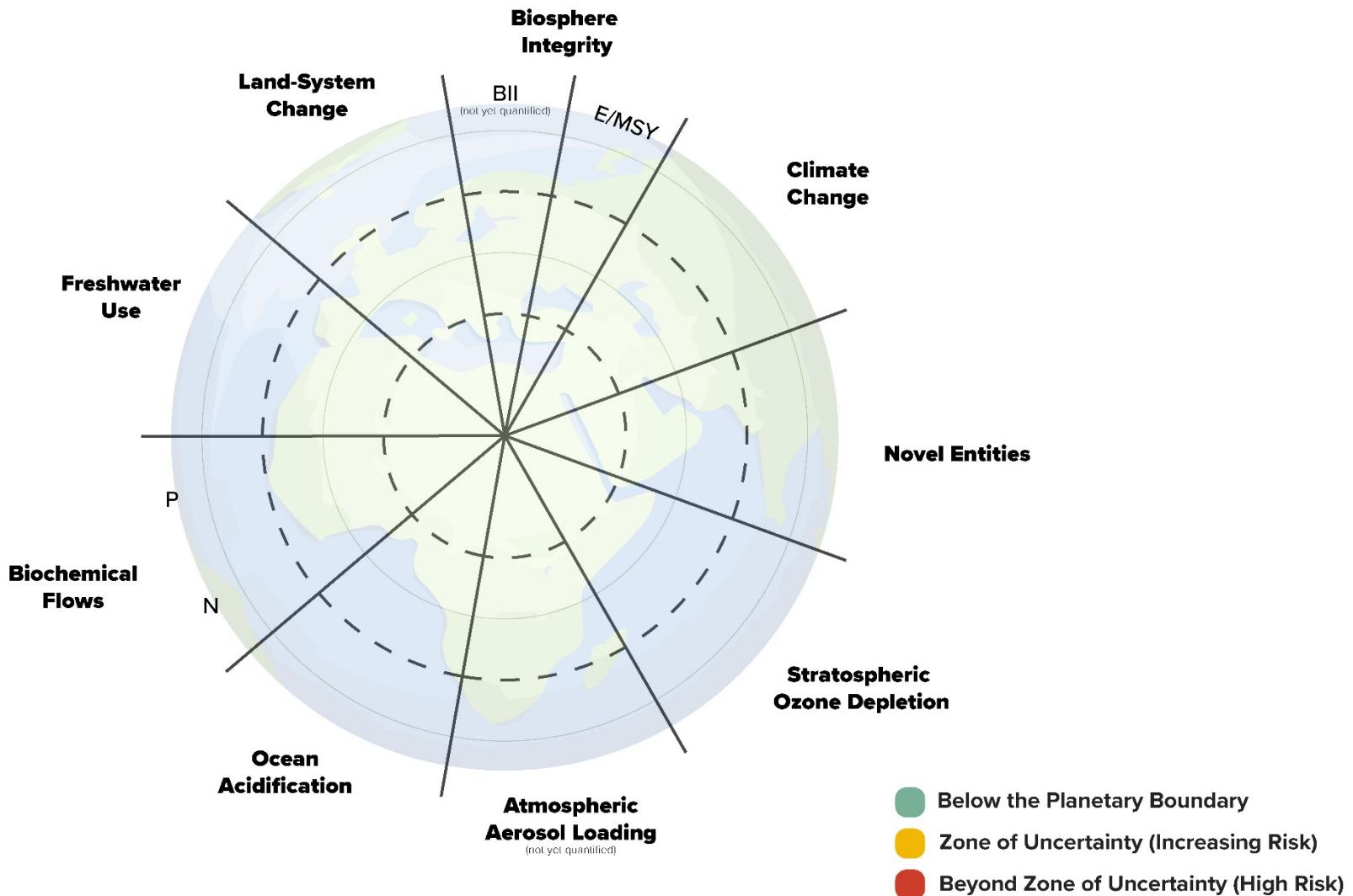
Planetary Boundaries

Concept

- First proposed by researchers led by Johan Rockström from the Stockholm Resilience Centre in 2009
- Quantitative planetary boundaries within which future generations can continue to exist
 - Based on nine indicators that are of high importance for the stability and resilience of the Earth system
- Crossing these boundaries increases uncertainties about humanity's future and the risk of severe or irreversible environmental changes

Planetary Boundaries

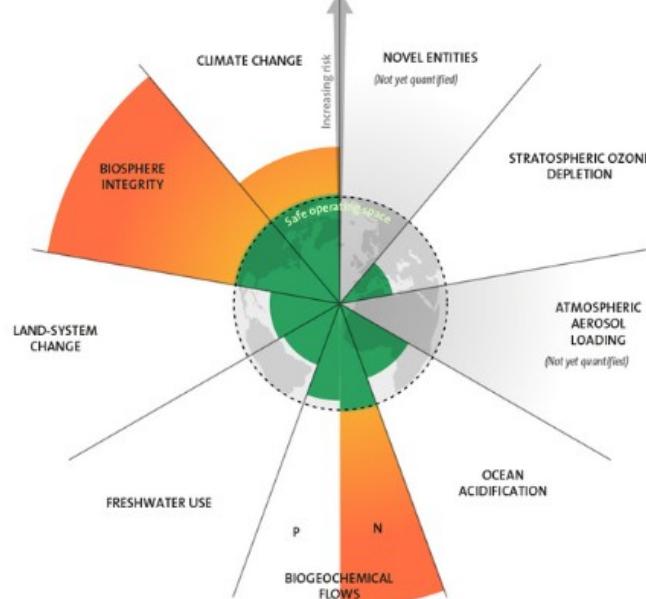
Concept



Source: Stockholm Resilience Centre, based on analysis in Persson et al. 2022 and Steffen et al. 2015.

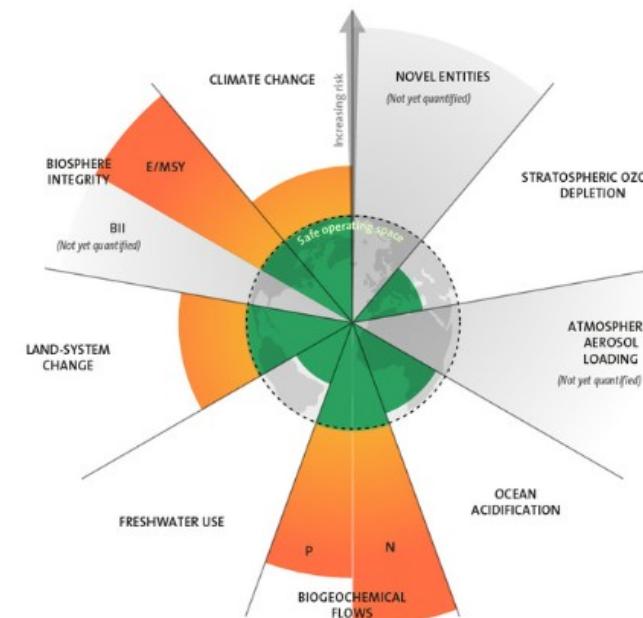
Planetary Boundaries

2009



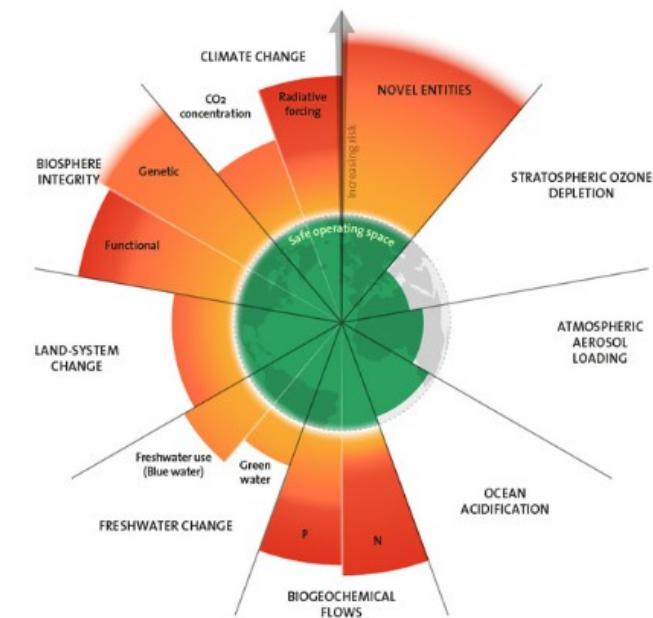
7 boundaries assessed,
3 crossed

2015



7 boundaries assessed,
4 crossed

2023



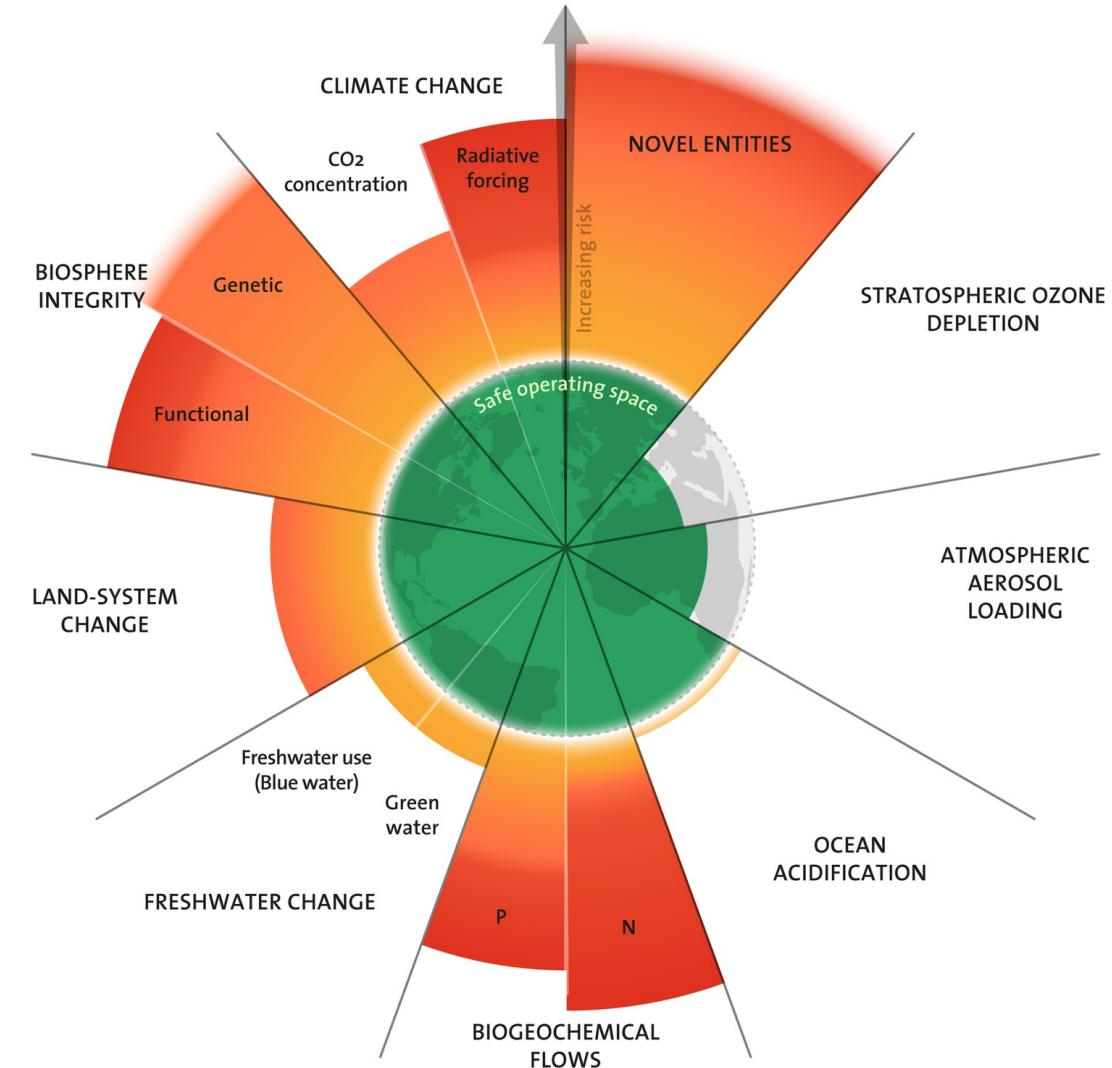
9 boundaries assessed,
6 crossed

The evolution of the planetary boundaries framework. Licensed under CC BY-NC-ND 3.0 (Credit: Azote for Stockholm Resilience Centre, Stockholm University. Based on Richardson et al. 2023, Steffen et al. 2015, and Rockström et al. 2009)

Planetary Boundaries

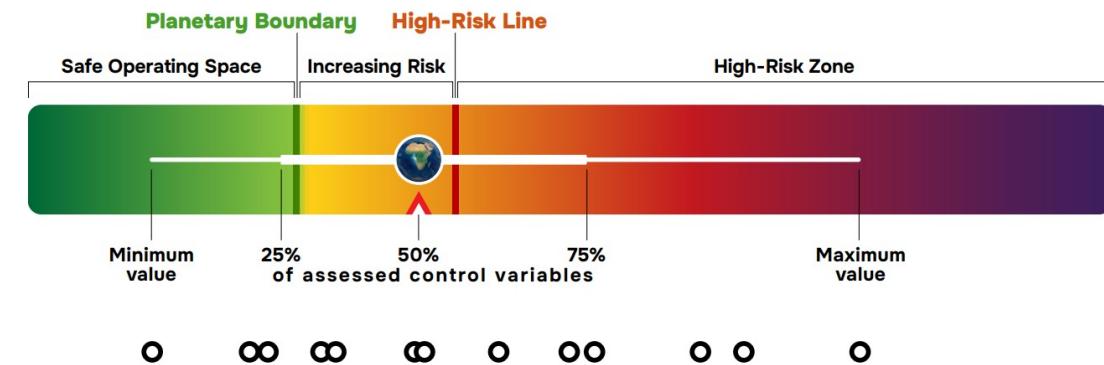
2025

- All boundaries are finally assessed
- Seven boundaries are now transgressed and pressure is increasing on all boundary processes → only exception is the ozone depletion and aerosol loading



Planetary Boundaries 2024

PLANETARY HEALTH AT A GLANCE



PLANETARY BOUNDARY PROCESSES

- Stratospheric Ozone Depletion
- Increase in Atmospheric Aerosol Loading
- Ocean Acidification
- Freshwater Change
Green Water
- Freshwater Change
Blue Water
- Land System Change
- Climate Change
CO₂ Concentration
- Climate Change
Radiative Forcing
- Modification of Biogeochemical Flows
Phosphorus Cycle
- Modification of Biogeochemical Flows
Nitrogen Cycle
- Introduction of Novel Entities
- Change in Biosphere Integrity
Functional Integrity
- Change in Biosphere Integrity
Genetic Diversity

L. Caesar*, B. Sakschewski*, L. S. Andersen, T. Beringer, J. Braun, D. Dennis, D. Gerten, A. Heilemann, J. Kaiser, N.H. Kitzmann, S. Lorani, W. Lucht, J. Ludescher, M. Martin, S. Mathesius, A. Paolucci, S. te Wierik, J. Rockström, 2024, Planetary Health Check Report 2024. Potsdam Institute for Climate Impact Research, Potsdam, Germany – CC BY 4.0.



WORLD3 MODEL

World3

History - System Dynamics

- Developed in the 1960s at MIT by Jay Forrester
- Methodology and mathematical modeling technique
- Used to understand the nonlinear behaviour of complex systems over time
 - e.g., Forrester created a model called World2

World3

History - System Dynamics

- System Dynamics modeling starts with defining *levels* (stocks) and their *rates* (flows)
- “*Laundry lists*” specify the set of influencing factors for each of the rate variables

World3

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- “*Laundry lists*” specify the set of influencing factors for each of the rate variables
- Levels:
 - Population (Inflows: Birth rate | Outflows: Death rate)
 - Money (Inflows: Income | Outflows: Expenses)

World3

History - System Dynamics

- System Dynamics modeling starts with defining *levels* (stocks) and their *rates* (flows)
- “*Laundry lists*” specify the set of influencing factors for each of the rate variables
- Levels:
 - Population (Inflows: Birth rate | Outflows: Death rate)
 - Money (Inflows: Income | Outflows: Expenses)
- Laundry list for “Birth rate”:
 - Population
 - Standard of living
 - Food Quality
 - Food Quantity
 - Education
 - Contraceptives

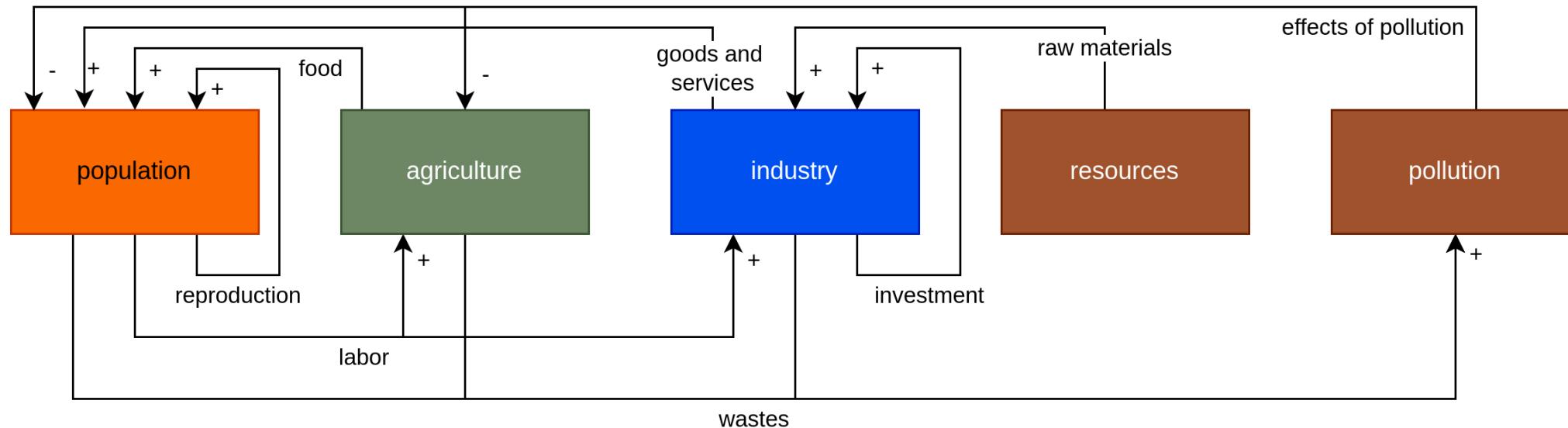
World3

History - World2 to World3

- The Club of Rome (non-governmental organization – NGO) invites Forrester to apply his ideas to the global economy and ecosystem → declines and proceeds with the project without the Club of Rome.
- Dennis Meadows (colleague and former student of Forrester) organizes the project for The Club of Rome.
- 17 researchers spend a year refining and enlarging the Forrester World2 model → World3.
- World3 is considerably more complex and more powerful

World3

Model Components



World3

Overview

- ca. 150 equations that govern the model
- 5 main sectors
 - Population
 - Agriculture
 - Industry
 - Resources
 - Pollution
- Covers the period from 1900 to 2100
- Written in a language called DYNAMO

World3

Population

- People
- Control mechanisms:
 - Birth rates
 - Death rates
 - Maturation → carrying people from one age category to the next

World3

Agriculture

- Arable land
- Control mechanisms:
 - Cultivation of new land
 - Farmland lost due to, e.g., erosion and urban development

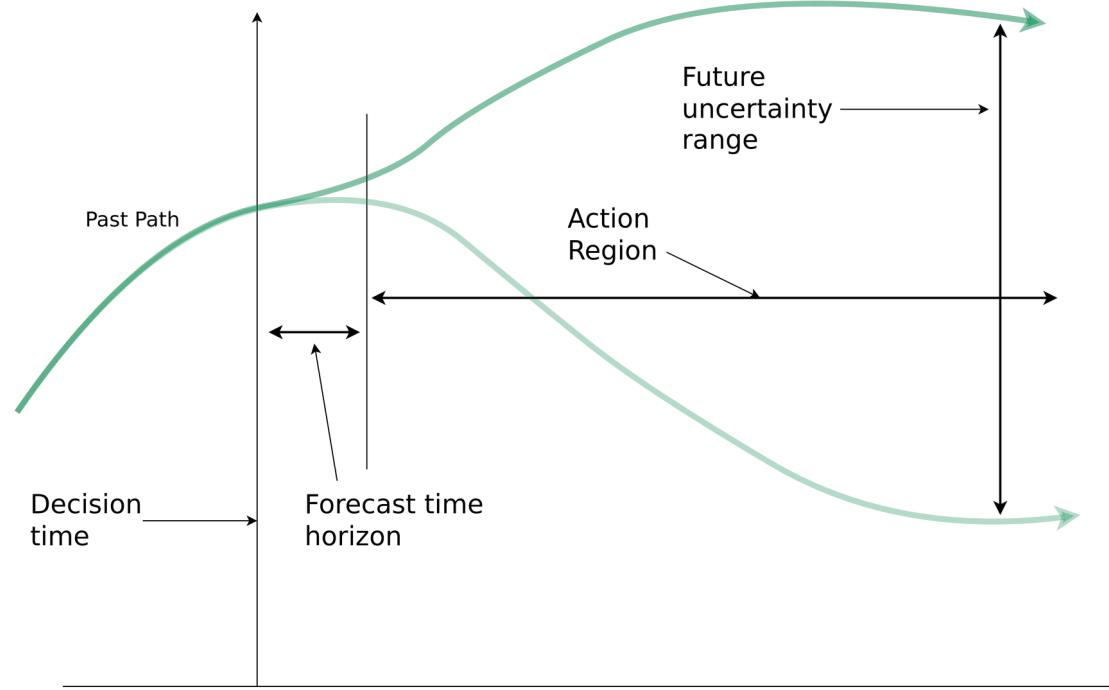
World3

Industry

- Capital (in USD) representing factories or other productive facilities
- Control mechanisms:
 - Investment input / inflow
 - Investment outflow / depreciation

World3

Forrester's Dilemma



“One can forecast future conditions in the region where action is not effective, and one can have influence in the region where forecasting is not reliable.” – Forrester, 2007

World3

Simulation Results

- Various scenarios based on different assumptions
- 4 popular scenarios:

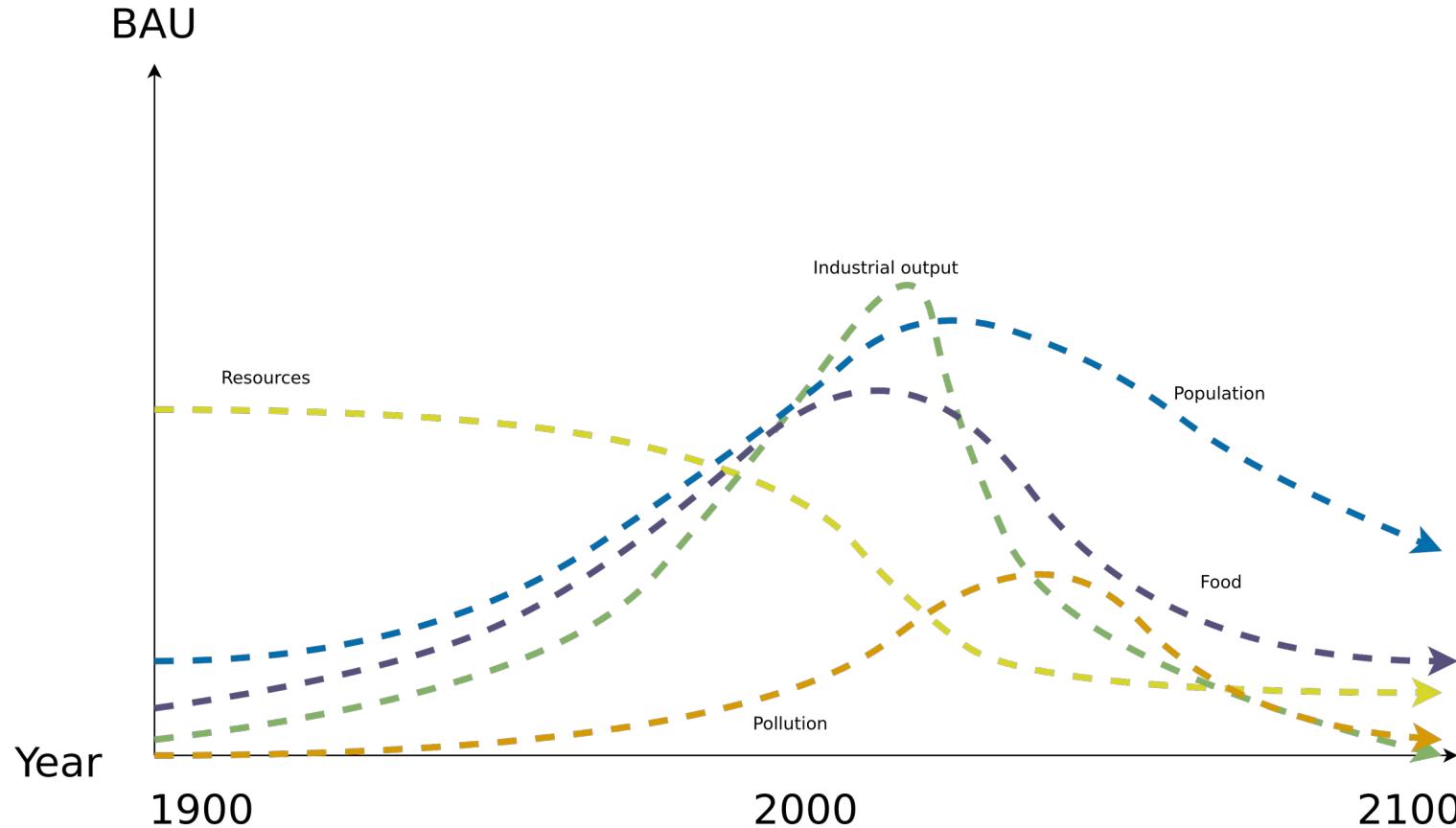
World3

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 - Business-as-usual (BAU)

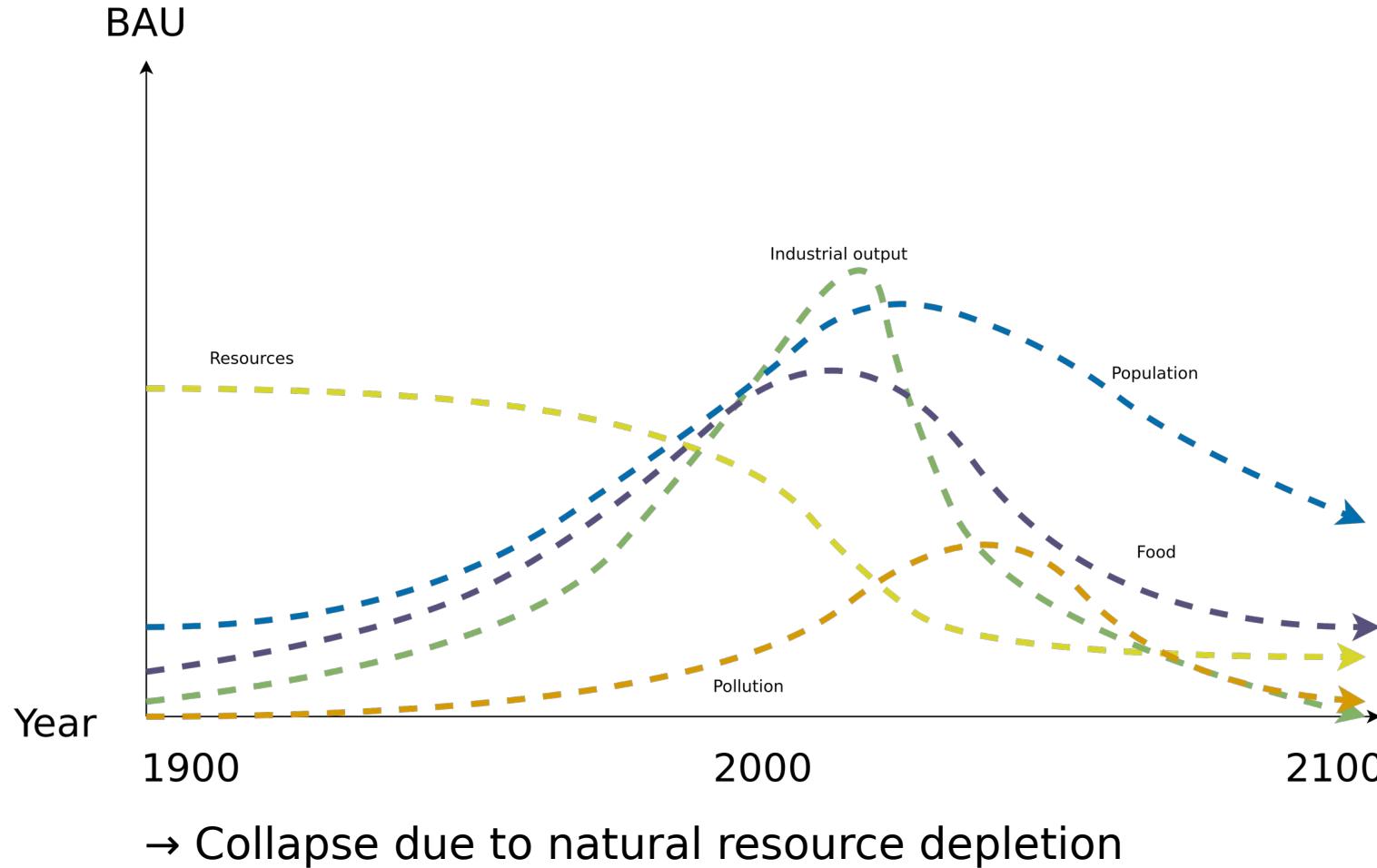
World3

Standard Run - Business-as-Usual (BAU)



World3

Standard Run – Business-as-Usual (BAU)



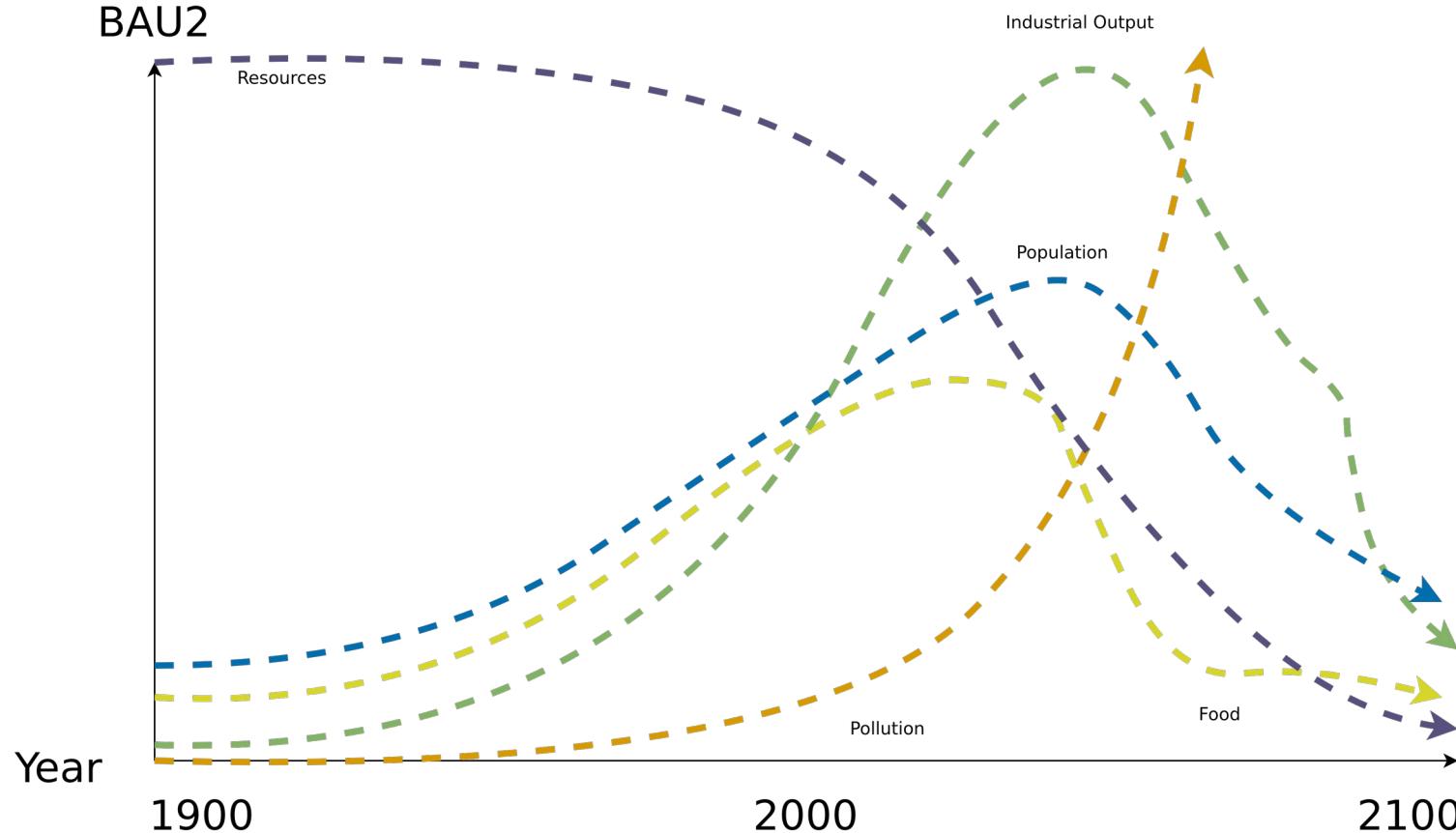
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Simulation Results

- Various scenarios based on different assumptions
- 4 popular scenarios:
 - Business-as-usual (BAU)
 - Business-as-usual2 (BAU2) → double the natural resources of BAU

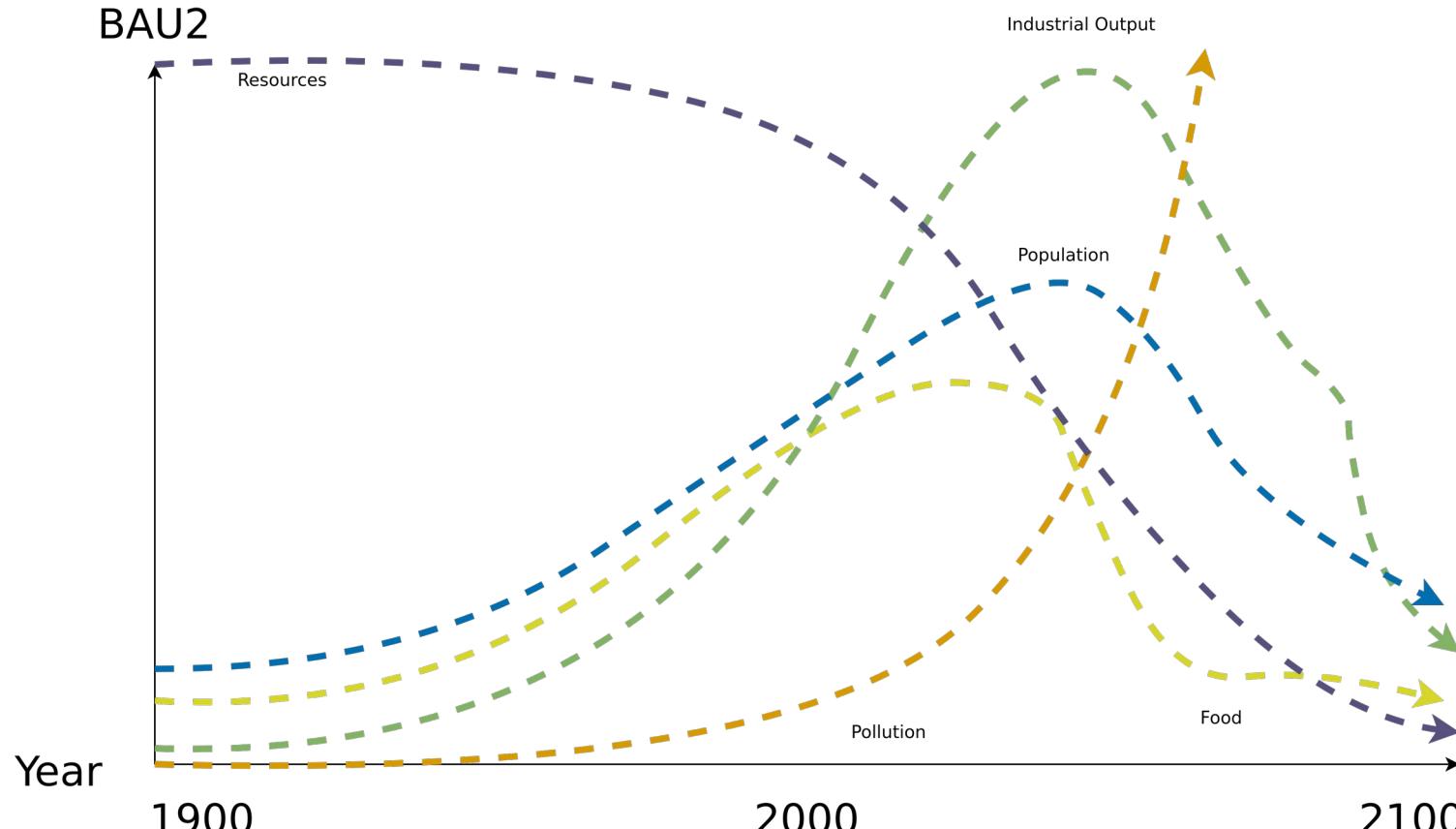
World3

Standard Run - Business-as-Usual2 (BAU2)



World3

Standard Run - Business-as-Usual2 (BAU2)



→ Collapse due to pollution (climate change equivalent)

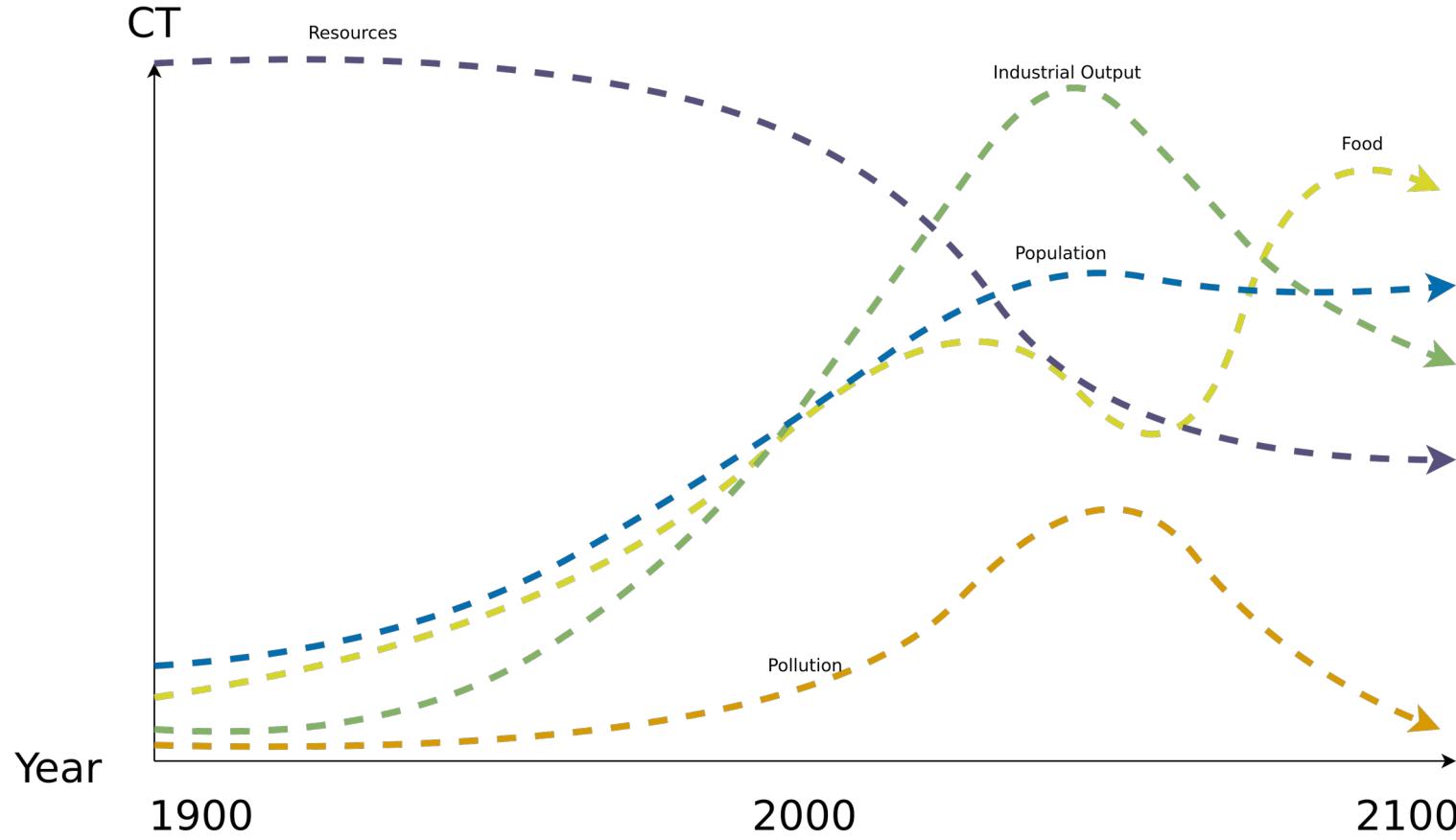
World3

Simulation Results

- Various scenarios based on different assumptions
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 - Business-as-usual2 (BAU2) → double the natural resources of BAU
 - Comprehensive Technology (CT) → BAU2 + exceptionally high technological development and adoption rates

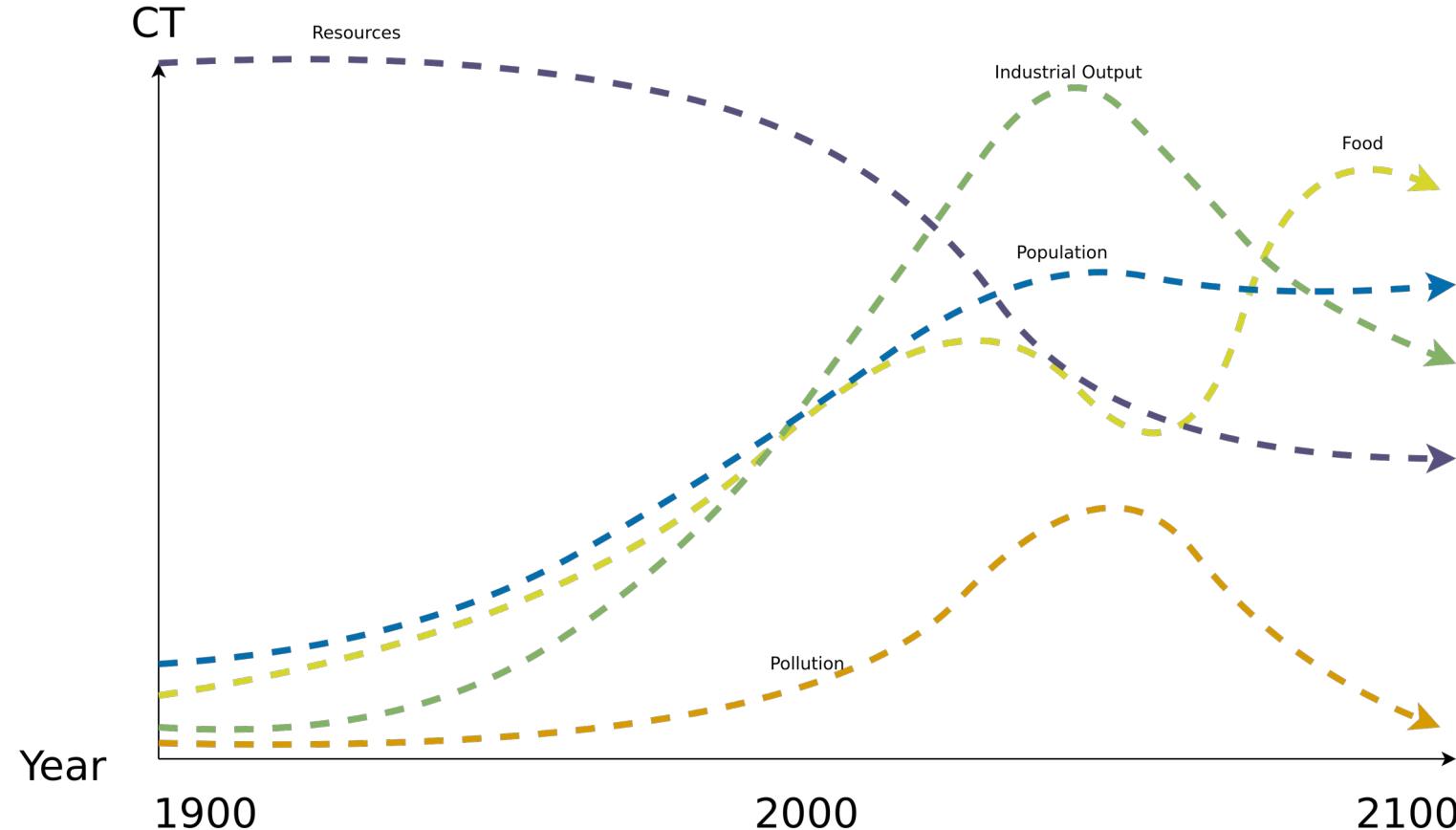
World3

Comprehensive Technology (CT)



World3

Comprehensive Technology (CT)



→ Rising costs for technology eventually causes declines, but no collapse

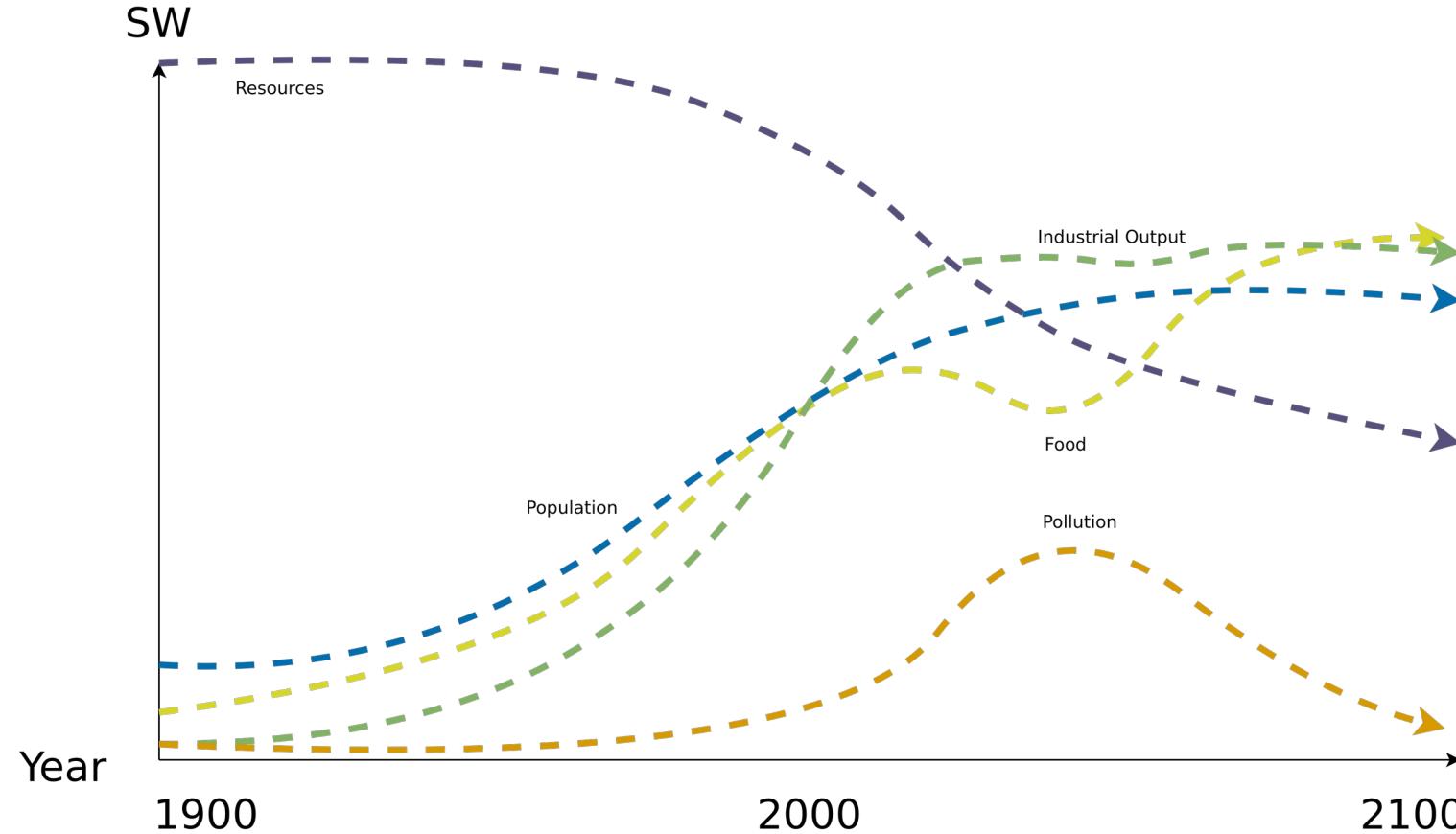
World3

Simulation Results

- Various scenarios based on different assumptions
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 - Stabilized World (SW) → CT + changes in societal values and priorities

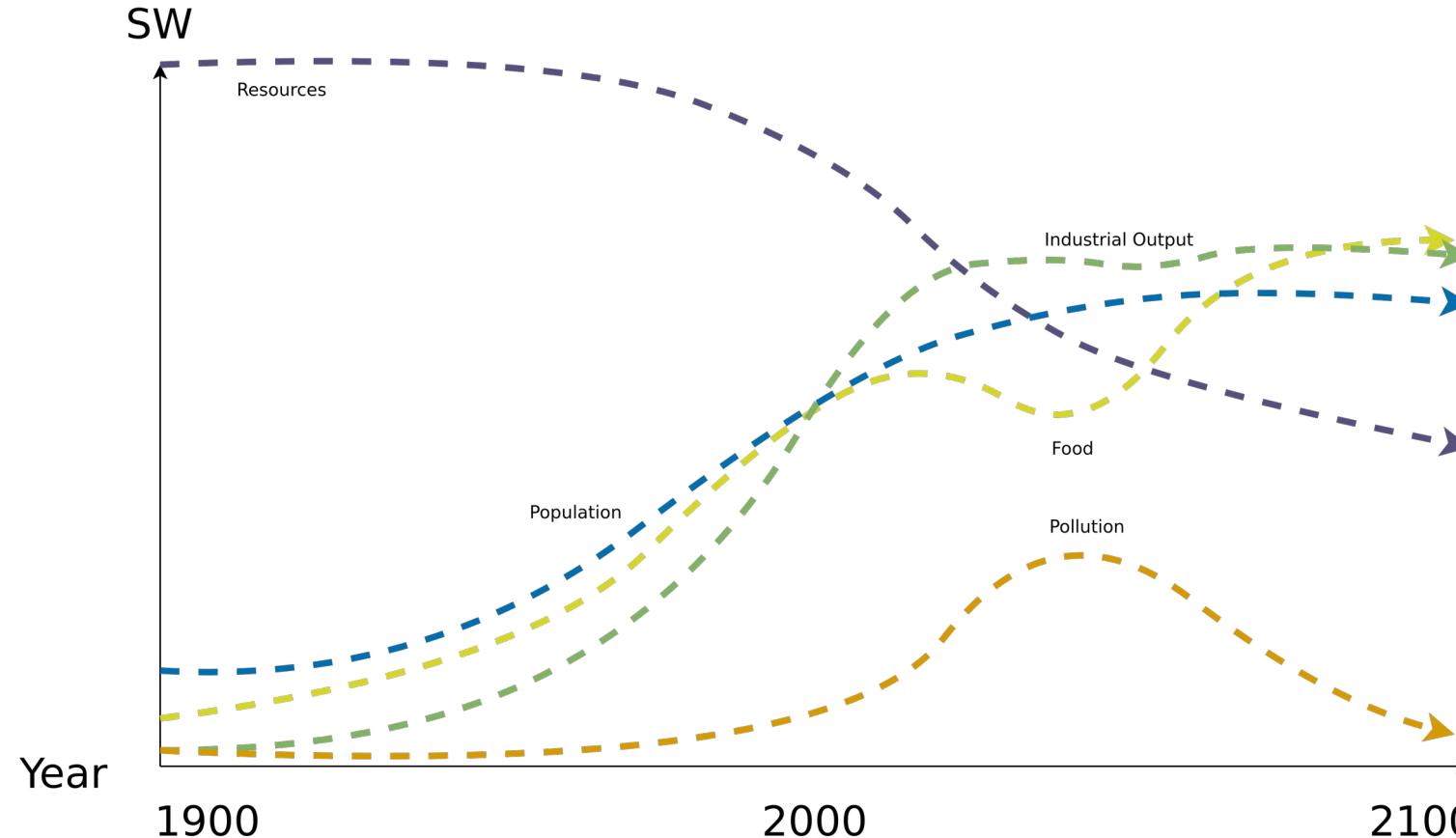
World3

Stabilized World (SW)



World3

Stabilized World (SW)



→ Population stabilizes in the twenty-first century, as does human welfare on a high level

World3

Simulation Results

- Various scenarios based on different assumptions
- 4 popular scenarios:
 - Business-as-usual (BAU)
 - Business-as-usual2 (BAU2) → double the natural resources of BAU
 - Comprehensive Technology (CT) → BAU2 + exceptionally high technological development and adoption rates
 - **Stabilized World (SW)** → CT + changes in societal values and priorities

World3

Sustainability

- World3 indicates that we are already consuming resources at a faster pace than the planet is able to re-grow/generate them
- Standard of living is not sustainable
- Relieving limiting factors is not a solutions → Instead, it is an accelerator towards disaster
- Preventing the worst-case scenario by reducing consumption

World3

Where are we now?

- So which of the 4 scenarios is closest to our current situation?
 - a) BAU
 - b) BAU2
 - c) CT
 - d) SW

CRITICISM

Criticism

- Model criticized by its creators and others
- There is even a complete book dedicated to criticize the model → *Models of Doom: A Critique of the Limits to Growth.*
 - Fun fact: *Models of Doom* is longer than the book it criticizes (*Limits to Growth*)
- 1972 book did not contain the equations governing the World3 model
- Subsequently released in a further book in 1974 → Dynamics of Growth in a Finite World

Criticism

- Heavily criticized by economists → The model questions the fairytale of eternal economic growth
- Aggregated variables → one resource, one food, one pollutant, one population
- No geographic structure, no social distinctions. "Average food per capita."
- Lack of statistical analysis – no error bars
- Accused of being too complex and oversimplification

CONCLUSION

Conclusion

- Planetary Boundaries
- World3 (1972) → Modeling the world using System Dynamics
- 4 commonly used scenarios → BAU, BAU2, CT and SW
- SW → Goal
- Widespread criticism but the overall message of the World3 model still holds → unsustainable behavior of humans will lead to a collapse of society

Additional Resources

- Meadows (1972) - *The Limits to Growth*.
- Meadows, Randers and Meadows (2004) - *Limits to Growth - The 30-Year Update*.
- D. L. Meadows, W. W. Behrens (1974) - *Dynamics of Growth in a Finite World*.
- H. S. D. Cole, Christopher Freeman (1973). *Models of Doom: A Critique of the Limits to Growth*.
- Planetary Boundaries – Stockholm Resilience Center – [Link](#)
- Planetary Health Check Report 2024. Potsdam Institute for Climate Impact Research – [Link](#)
- Brian Hayes (2012) - Computation and the Human Condition (Harvard SEAS) – [Link](#)

Questions?