The Limits to Growth: Sustainability and the Circular Economy

Lecture 5: Limits to Growth and Planetary Boundaries

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M.Sc. Anant Sujatanagarjuna

License

INTRODUCTION

Introduction

Finite Systems – Sandbox / Playground

Introduction

Earth Overshoot Day

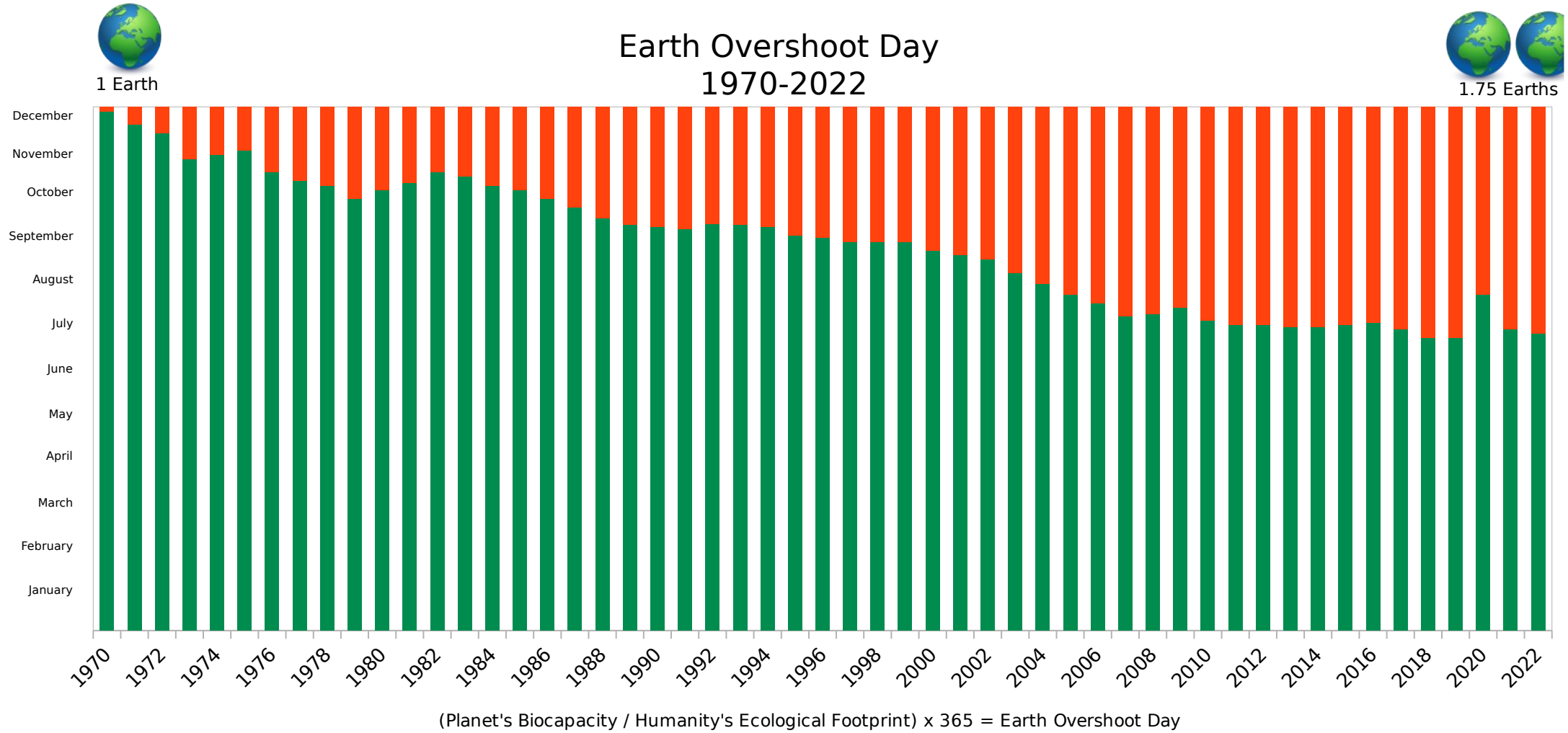


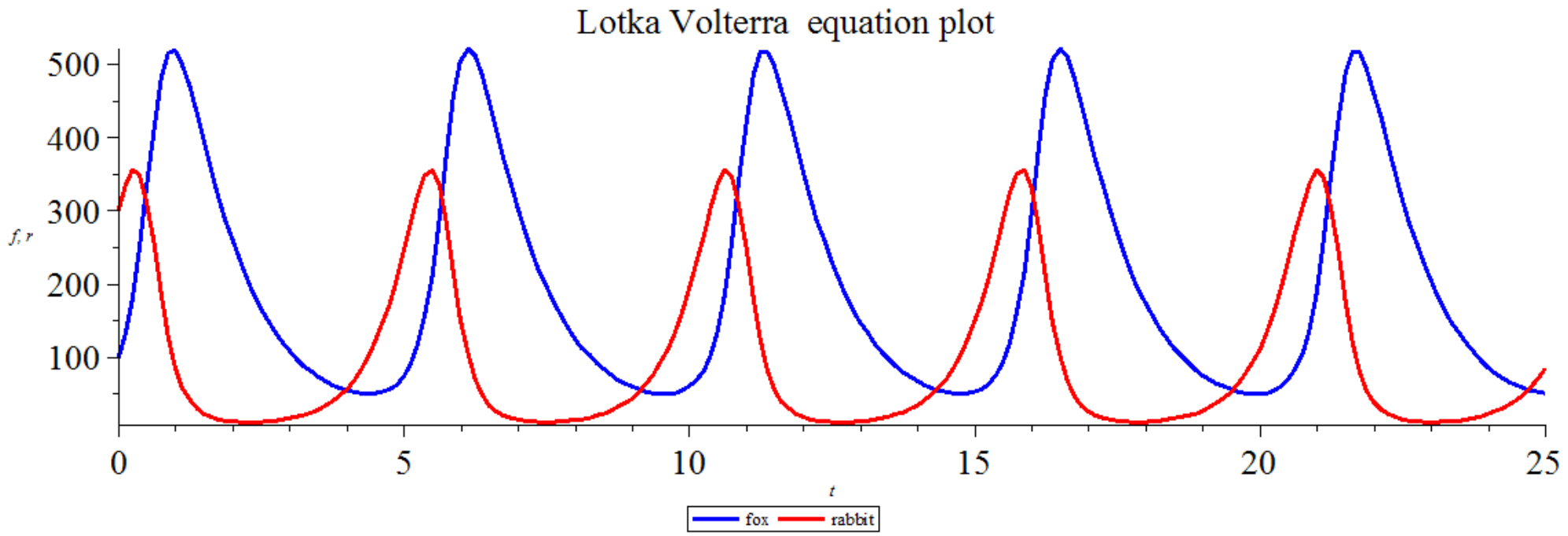
Figure adapted from https://www.overshootday.org/newsroom/past-earth-overshoot-days/

Introduction

Lotka–Volterra Equations (Predator–Prey Equations)

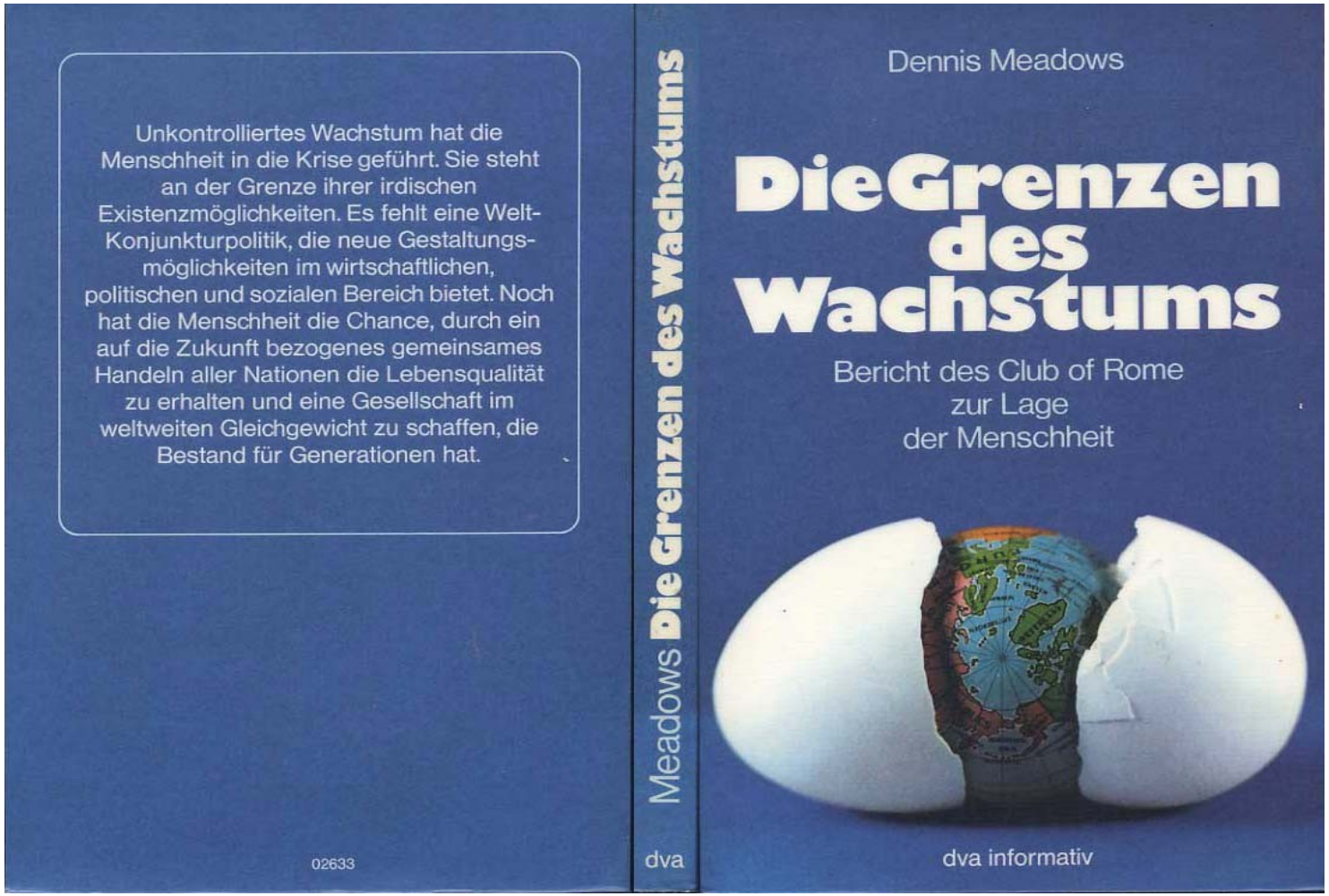
Introduction

Lotka–Volterra Equations (Predator–Prey Equations)



Introduction

The Limits to Growth – 1972



Introduction
The Limits to Growth

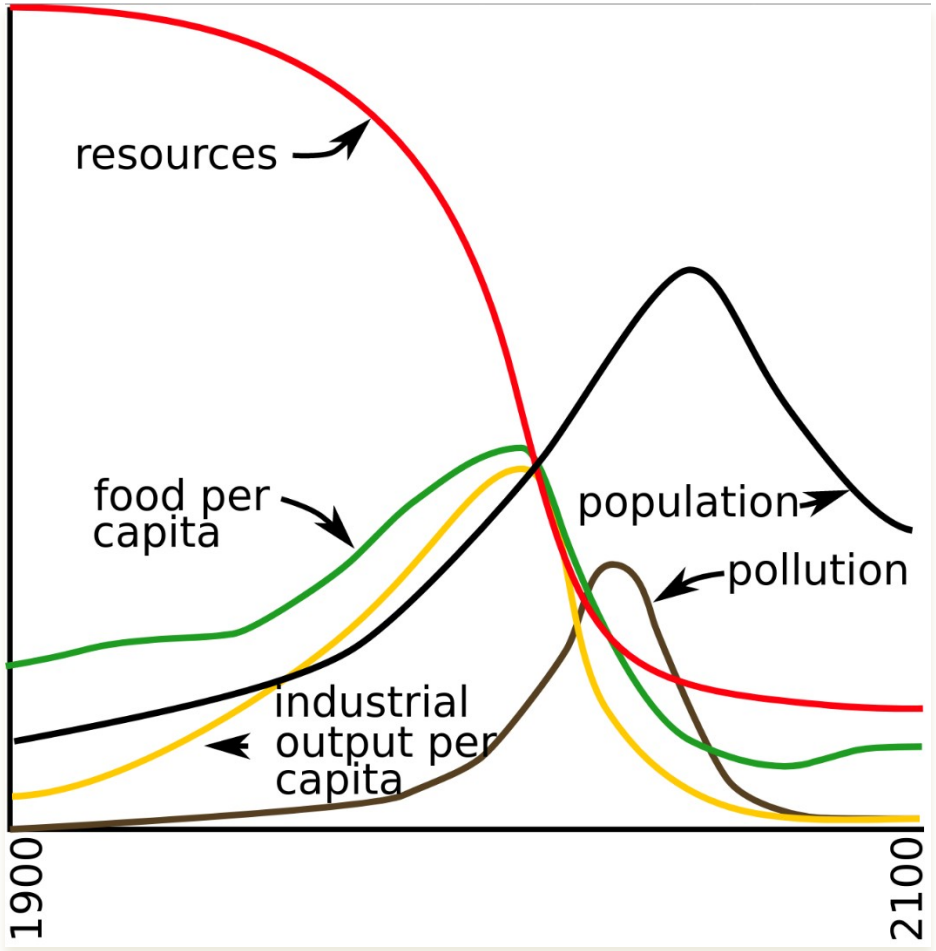
“If the present growth trends in world population, industrialization, pollution, food production, and resource depletion continue unchanged, ***the limits to growth on this planet will be reached sometime within the next one hundred years.***

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

Meadows (1972) – The Limits to Growth

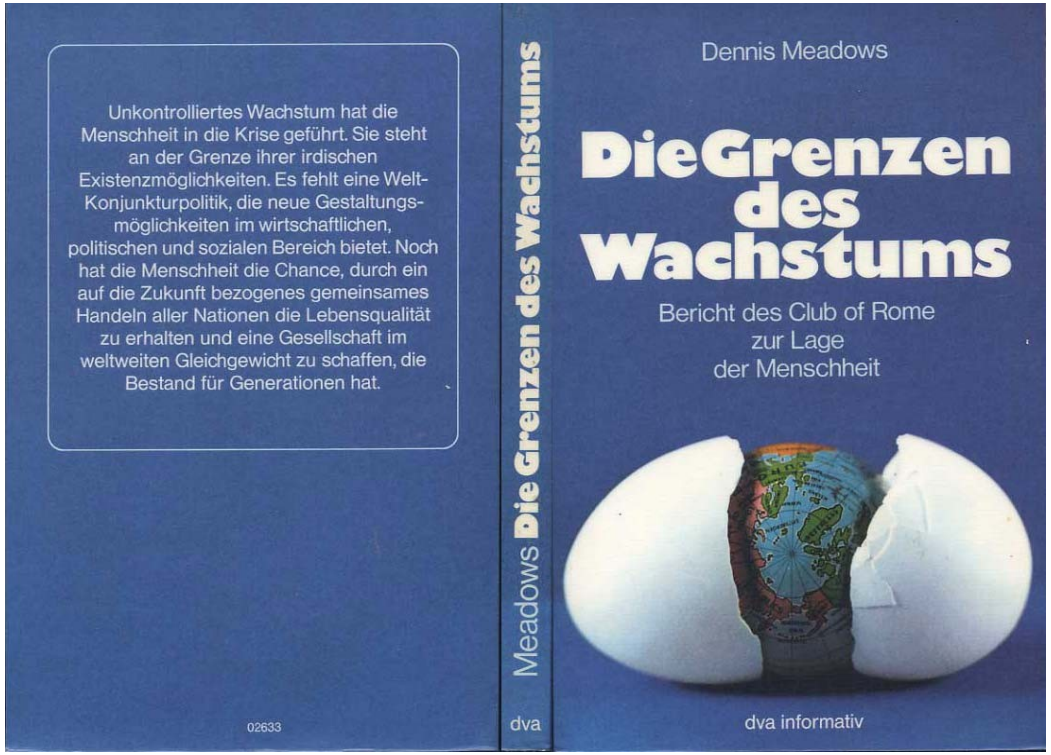
Introduction

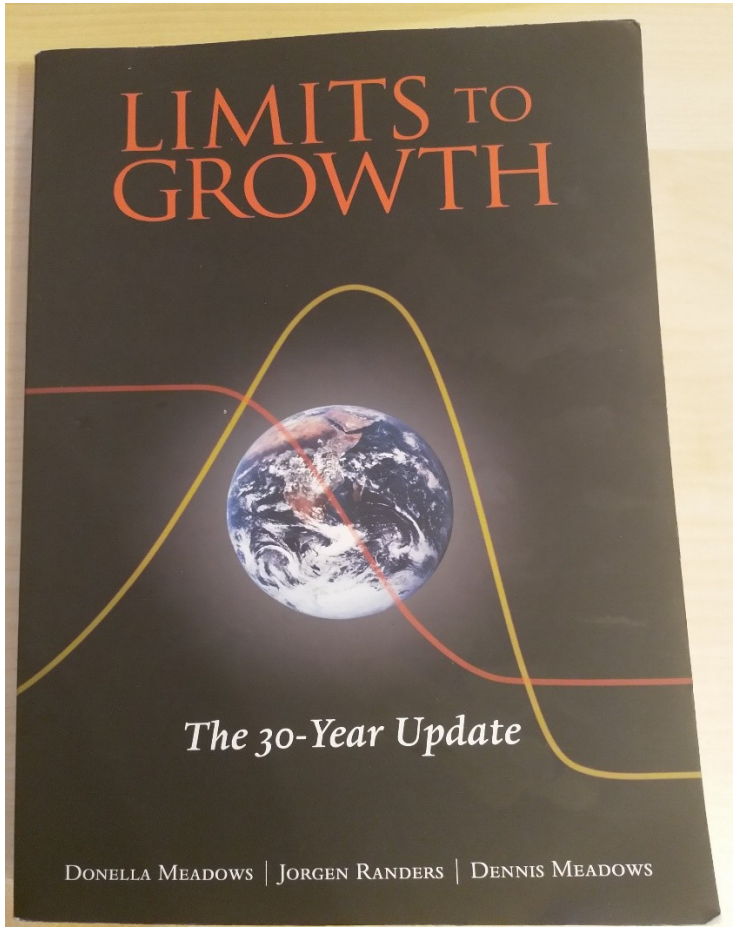
The Limits to Growth – World3 Standard Run



Introduction

The Limits to Growth – 1972 / 2004





Introduction

The Limits to Growth – World3 Model

Click Me

Click Me

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

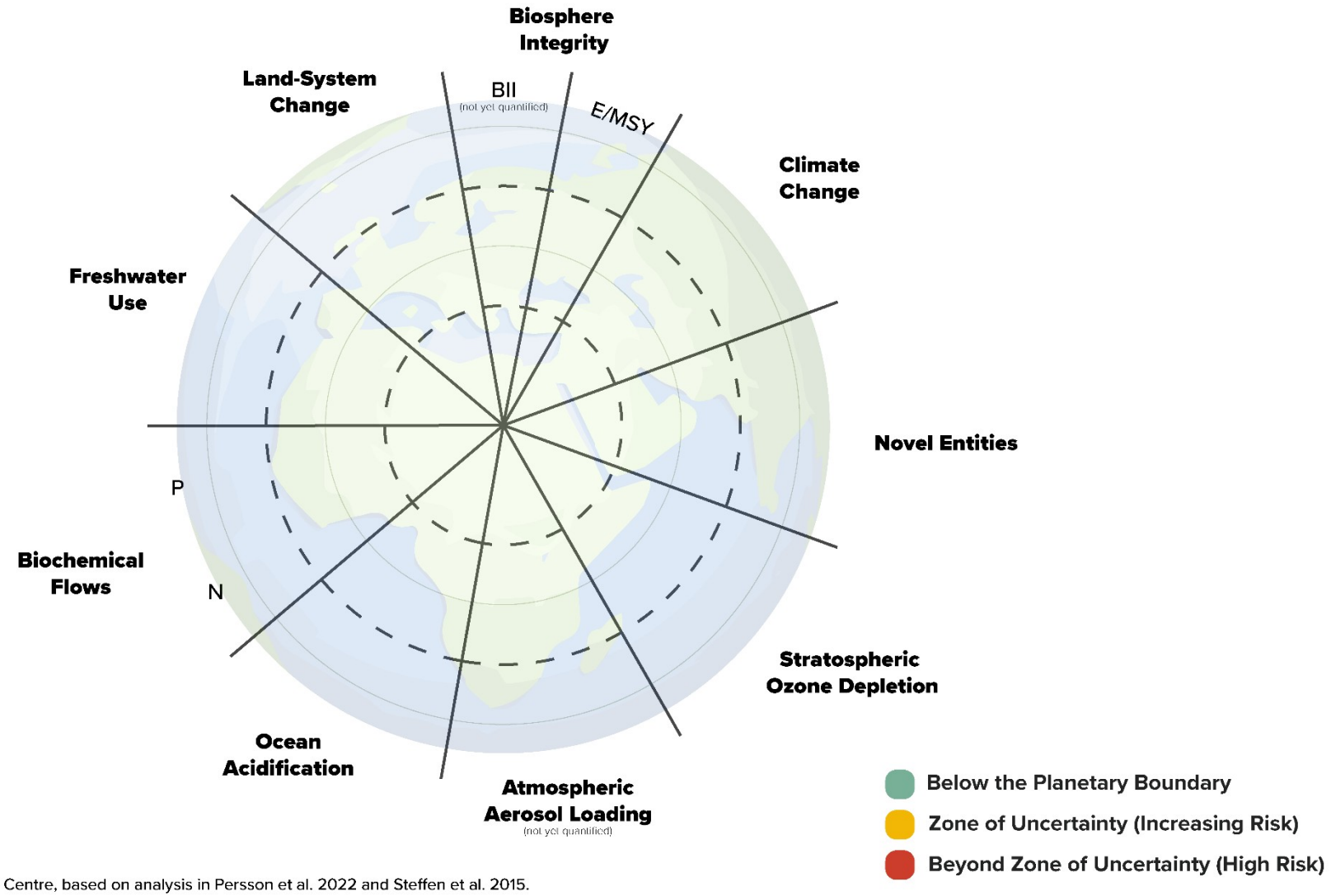
Planetary Boundaries

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

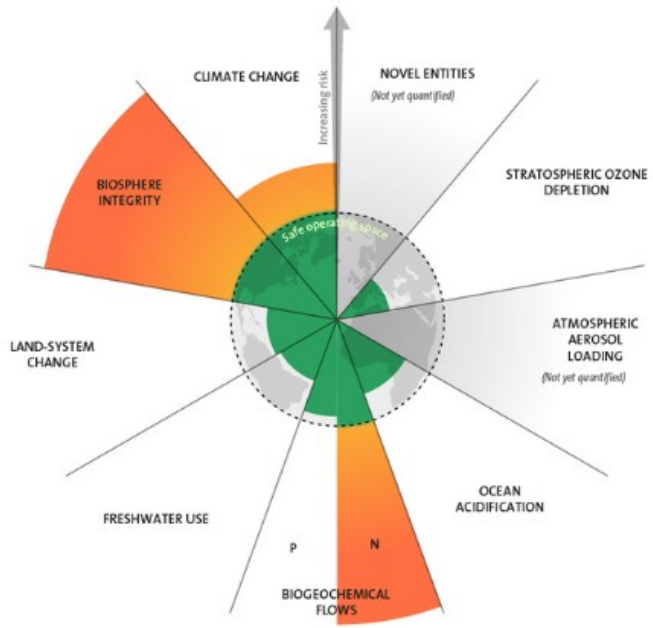
Concept



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

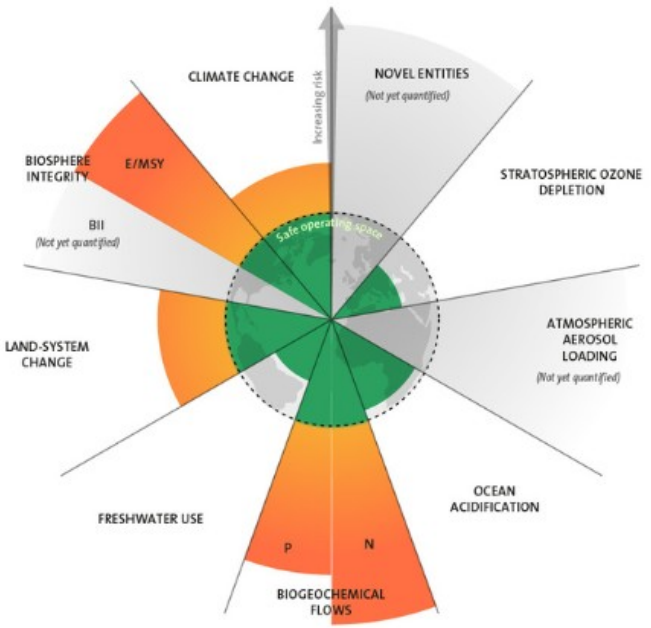
Planetary Boundaries

2009



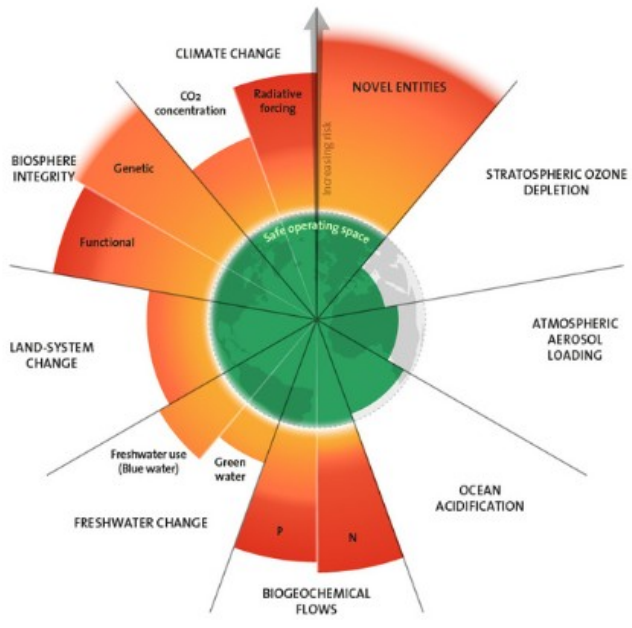
7 boundaries assessed,
3 crossed

2015



7 boundaries assessed,
4 crossed

2023

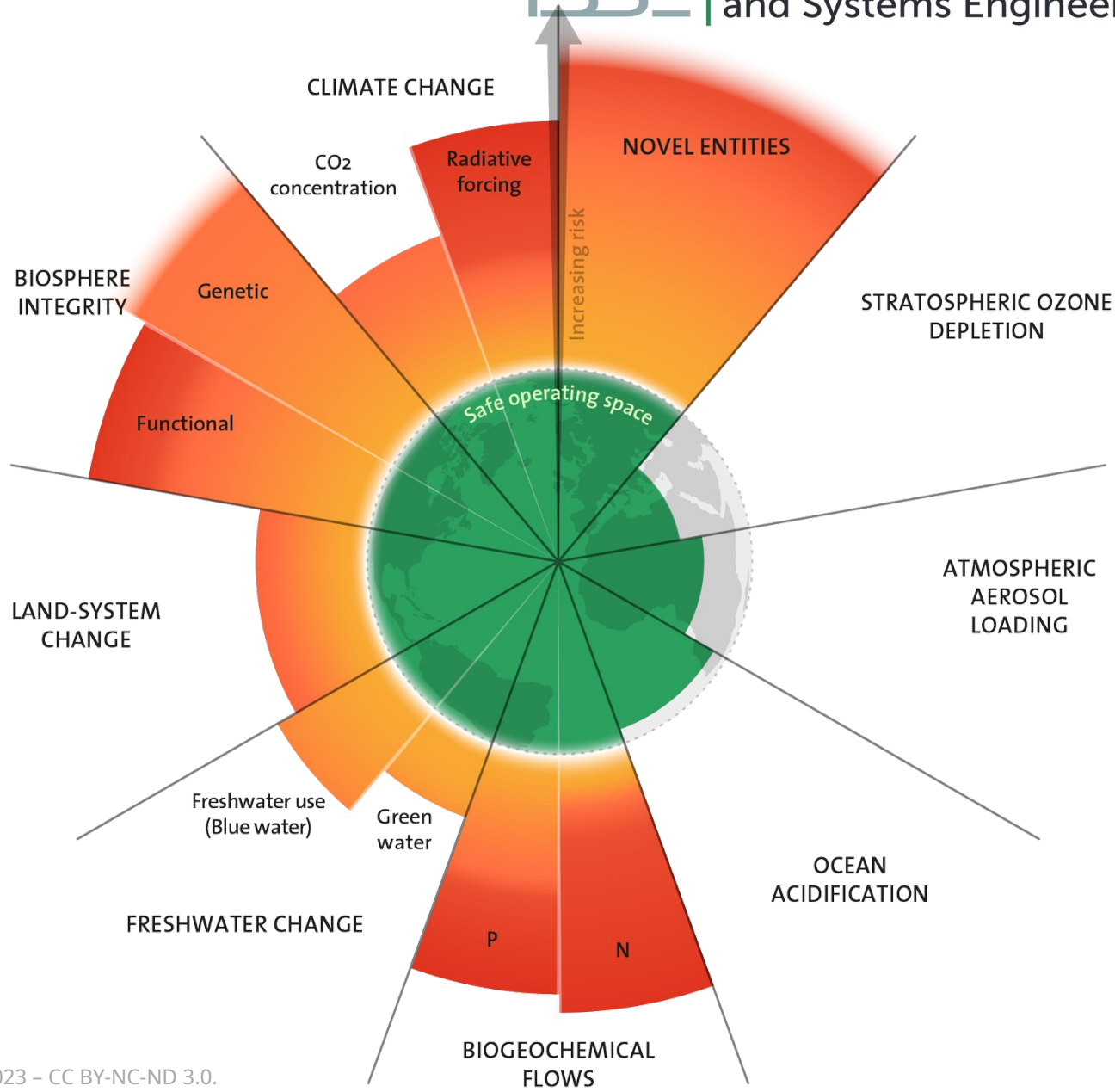


9 boundaries assessed,
6 crossed

The evolution of the planetary boundaries framework. Licenced 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
2023

- All boundaries are finally assessed
- Six boundaries are now transgressed and pressure is increasing on all boundary processes → only exeption is the ozone depletion



Azote for Stockholm Resilience Centre, based on analysis in Richardson et al 2023 – CC BY-NC-ND 3.0.

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

F. E. Cellier (2008) – World3 in Modelica: Creating System Dynamics Models in the Modelica Framework – Link

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)

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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

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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

Brian Hayes (2012) – Computation and the Human Condition (Harvard SEAS) – Link

World3

Model Components

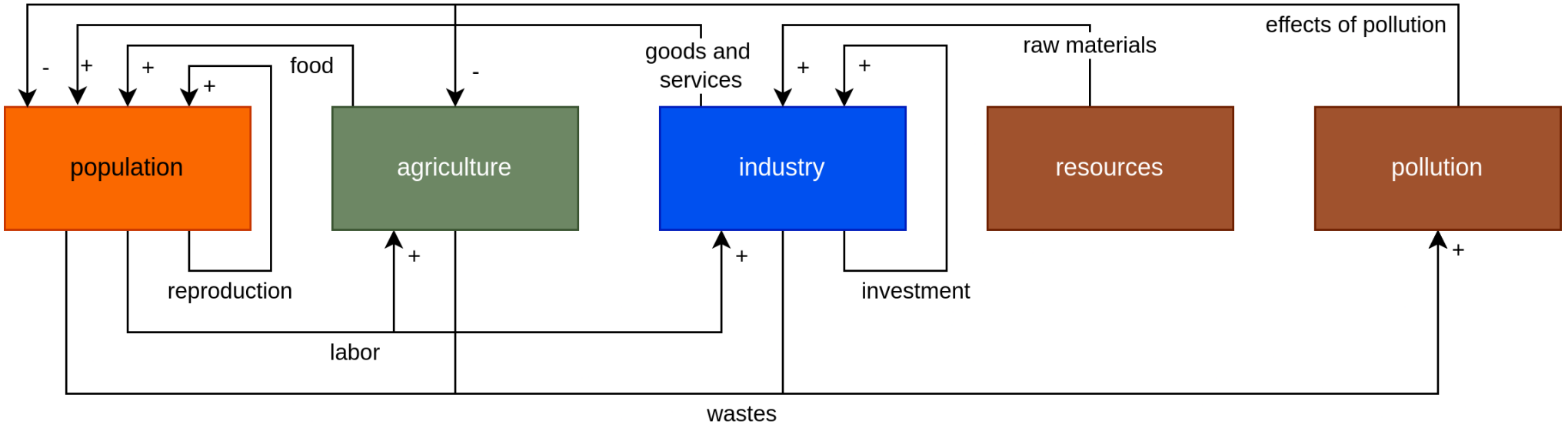


Image recreated from: Brian Hayes (2012) – Computation and the Human Predicament – Link

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

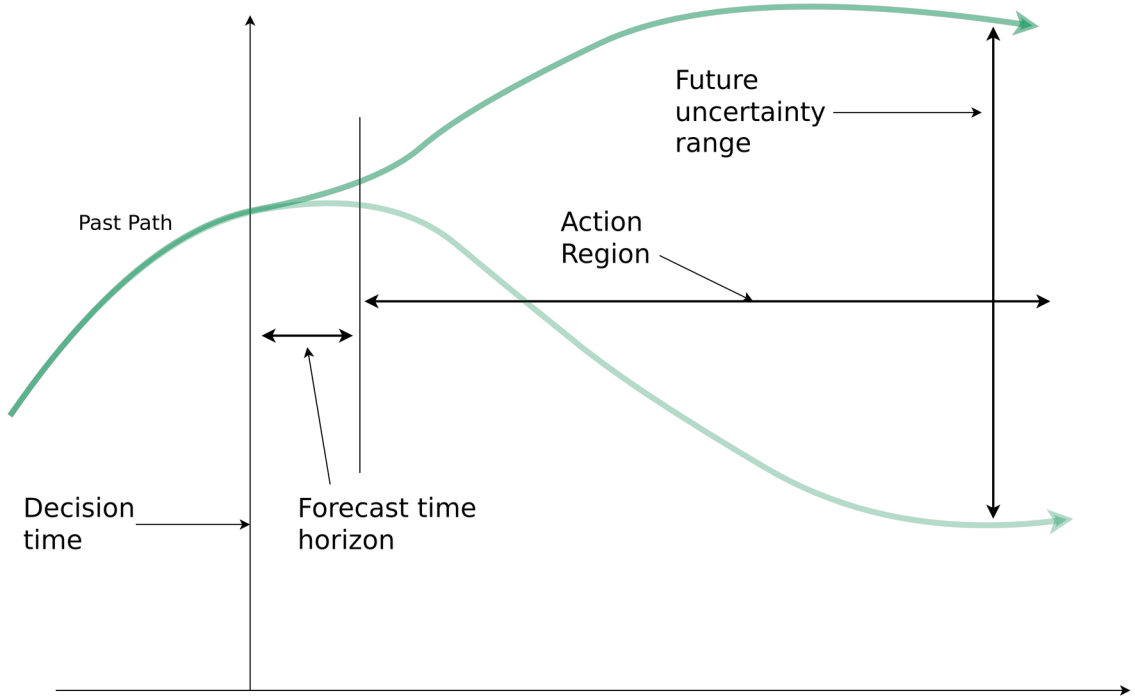
World3

Industry

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

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

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Simulation Results

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

World3

Simulation Results

- Various scenarios based on different assumptions
- 4 popular scenarios:
  - Business-as-usual (BAU)

World3

Standard Run – Business-as-Usual (BAU)

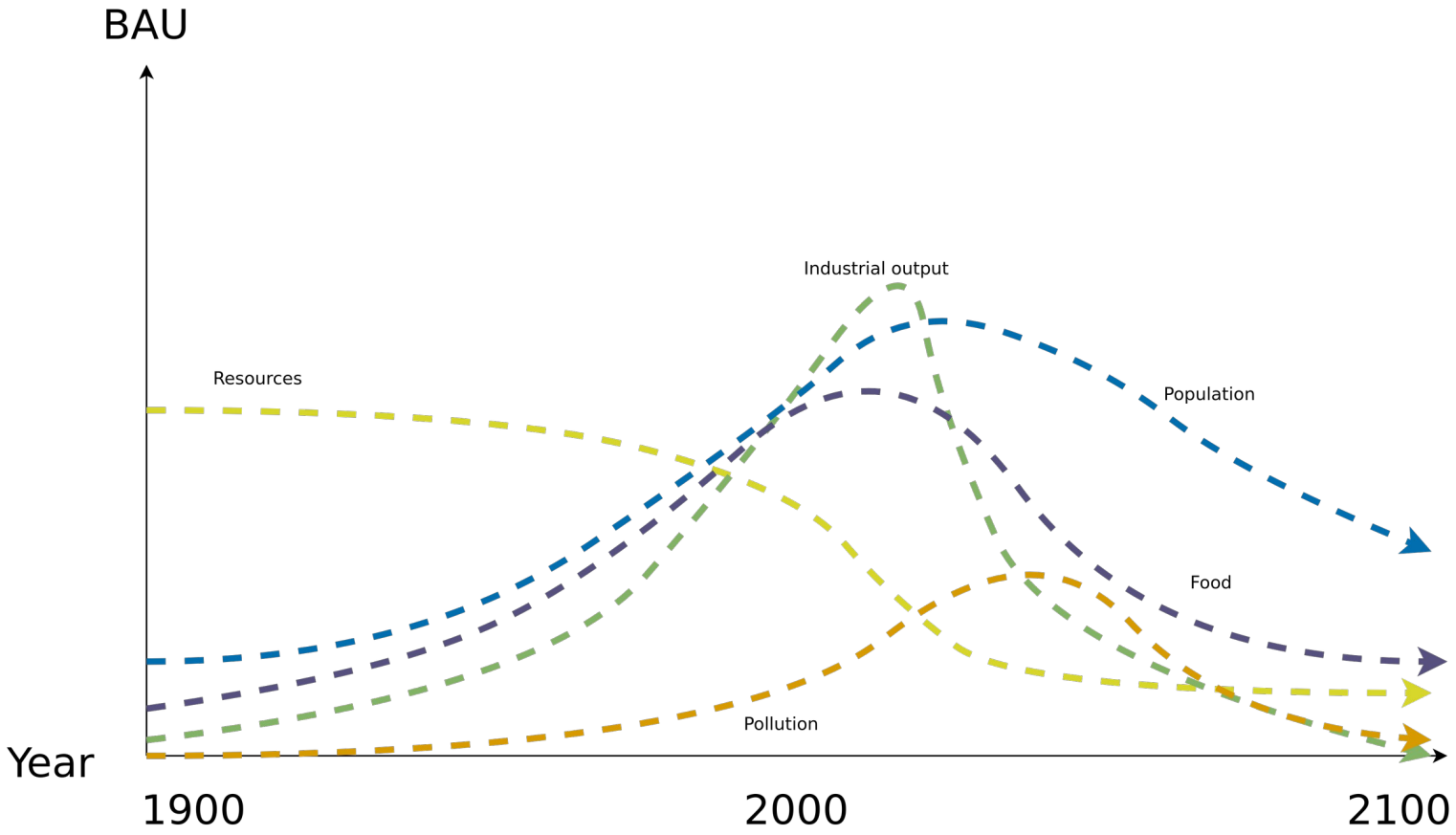

Image recreated from: Gaya Herrington (2020) – Update to limits to growth: Comparing the World3 model with empirical data – Link

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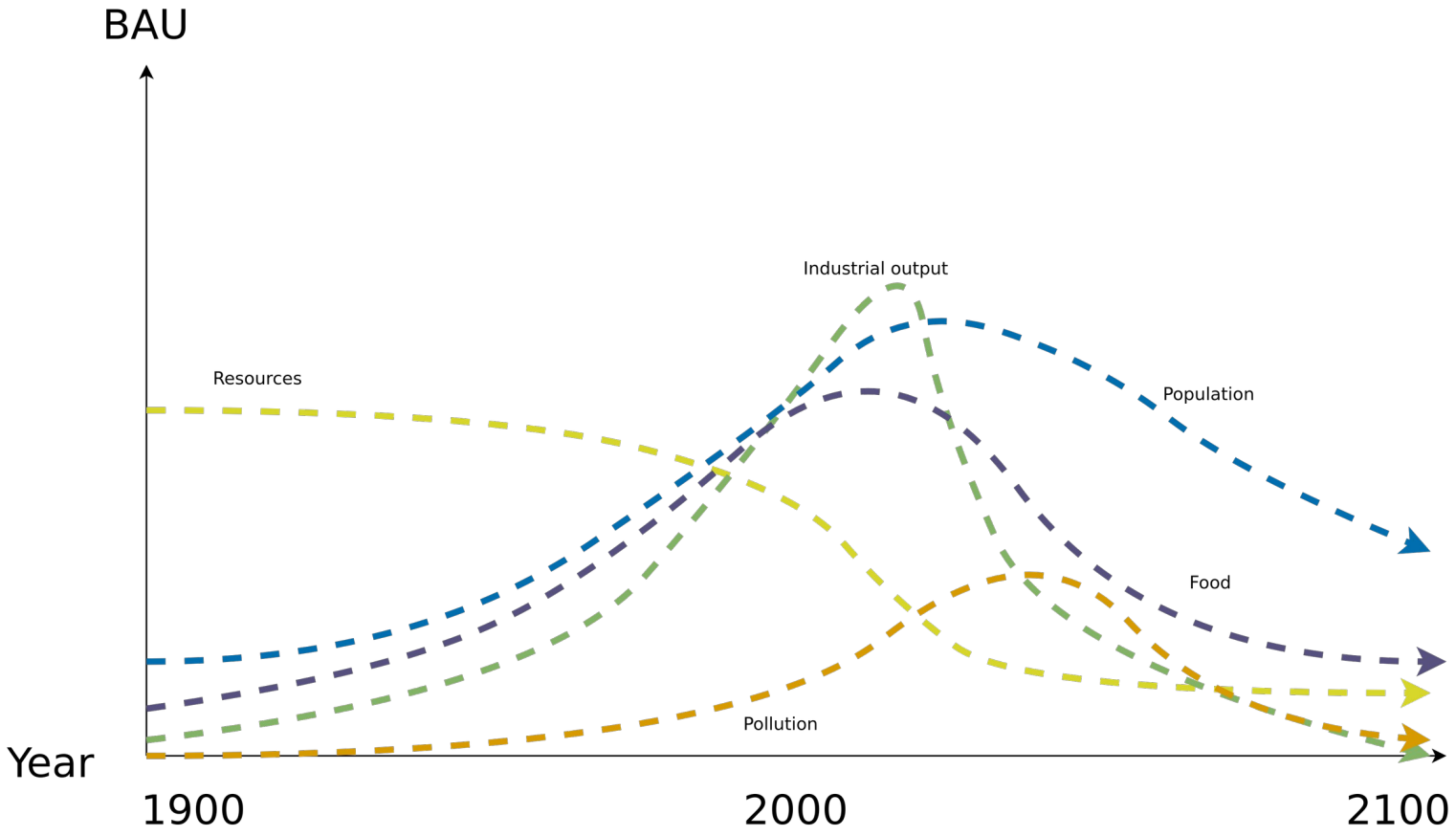
Standard Run – Business-as-Usual (BAU)



→ Collapse due to natural resource depletion

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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

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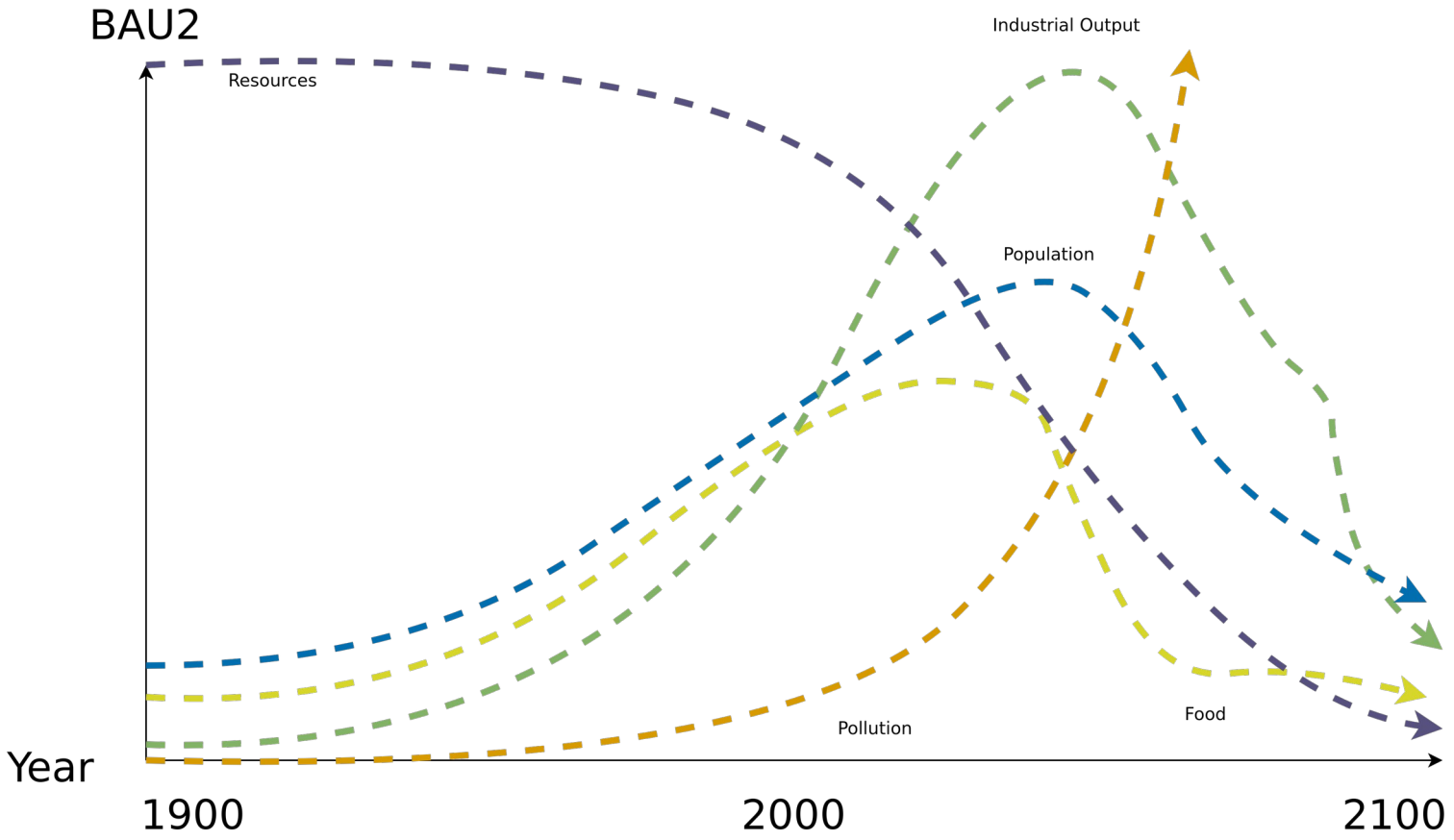
Standard Run – Business-as-Usual2 (BAU2)



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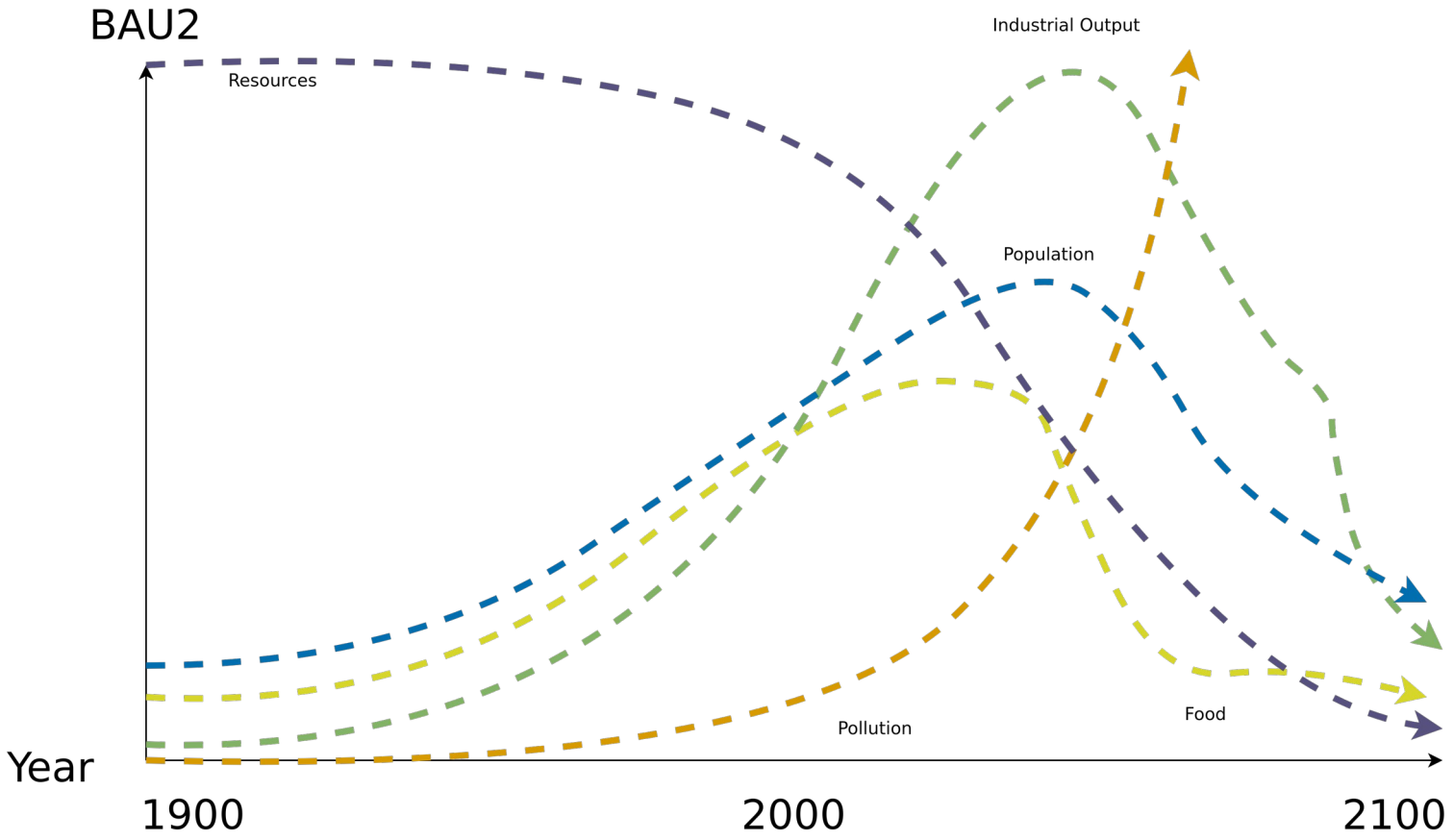
Standard Run – Business-as-Usual2 (BAU2)



→ Collapse due to pollution (climate change equivalent)

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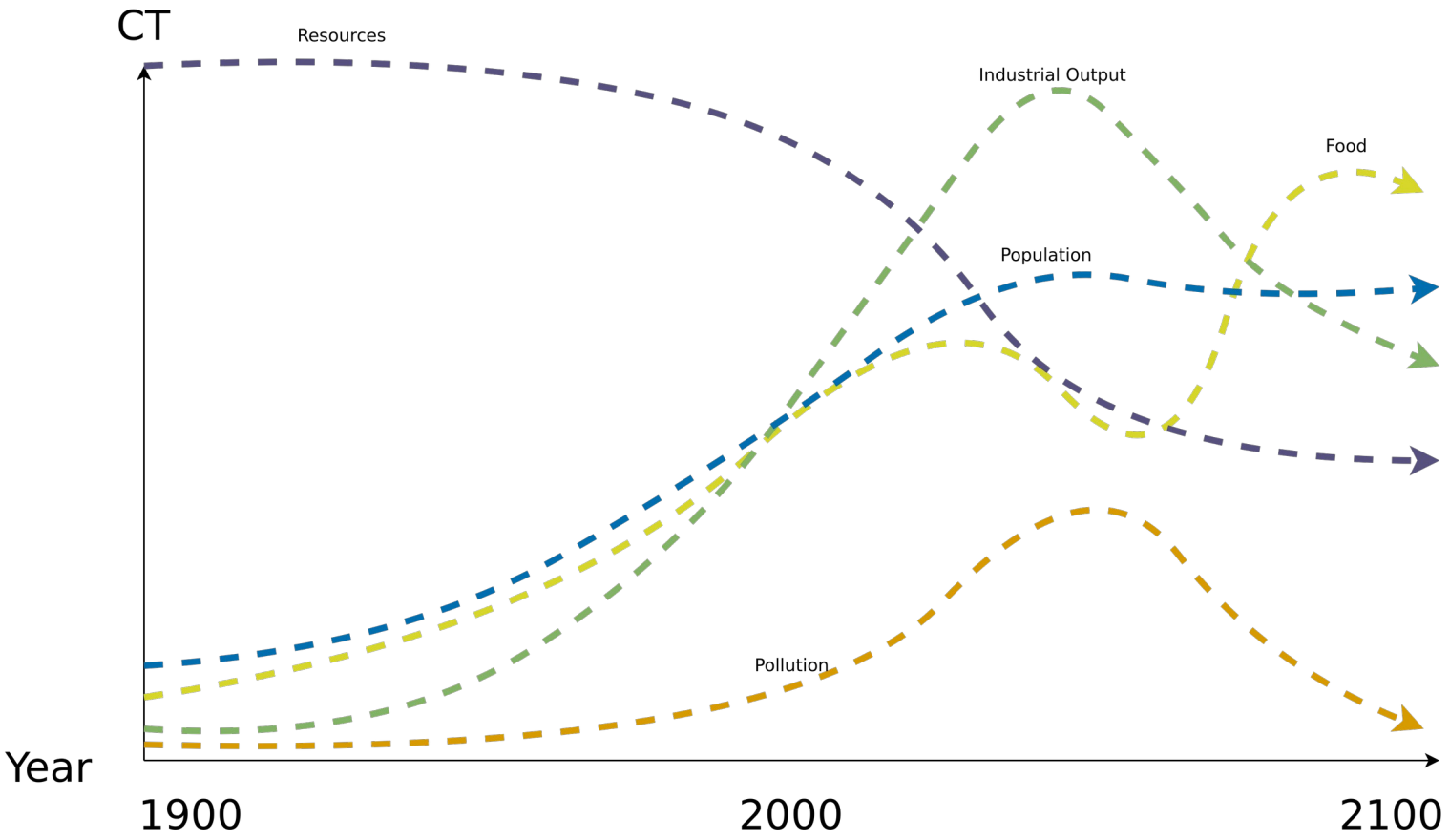
Simulation Results

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

World3

Comprehensive Technology (CT)



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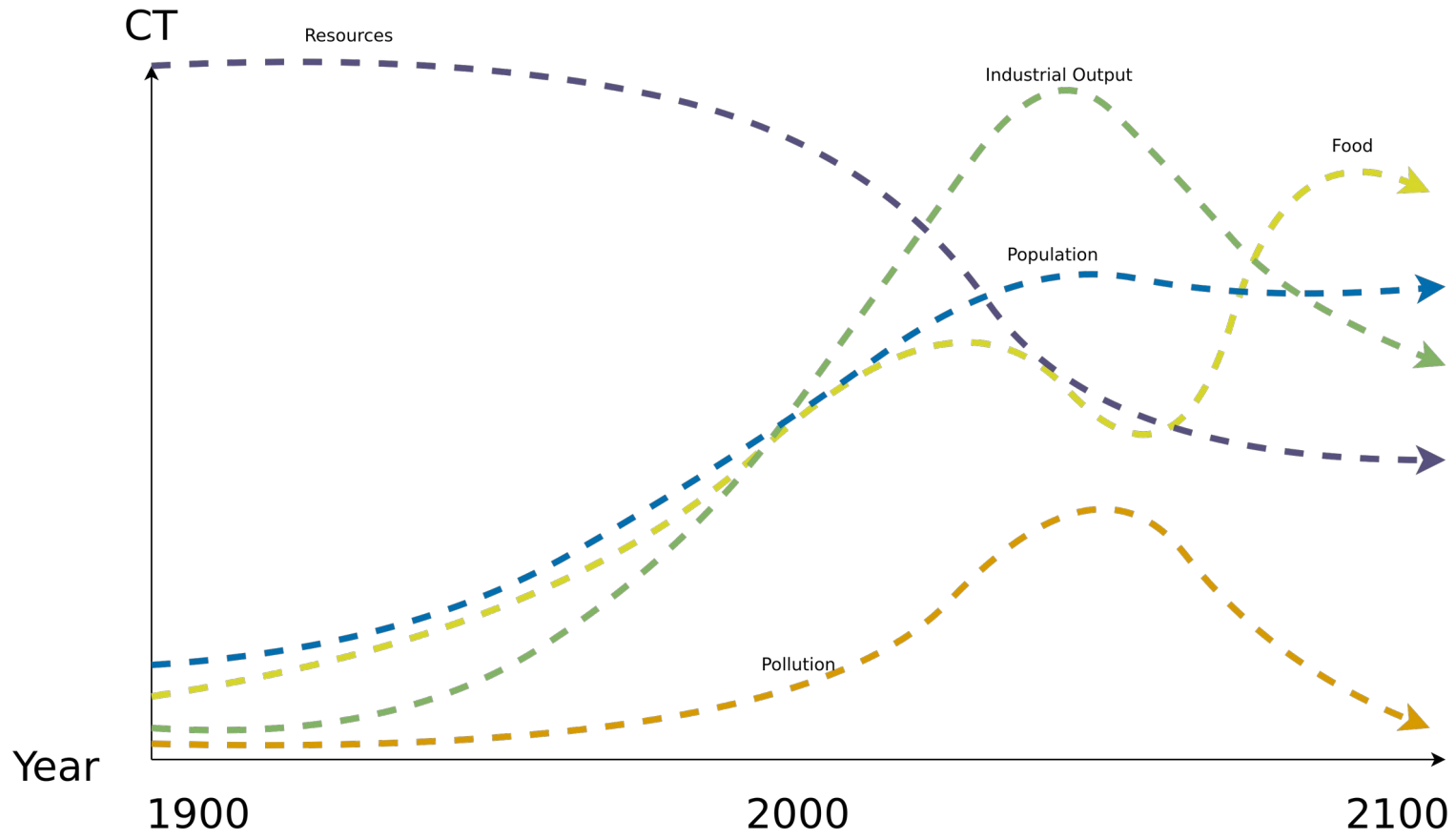
Comprehensive Technology (CT)



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

Image recreated from: Gaya Herrington (2020) – Update to limits to growth: Comparing the World3 model with empirical data – Link

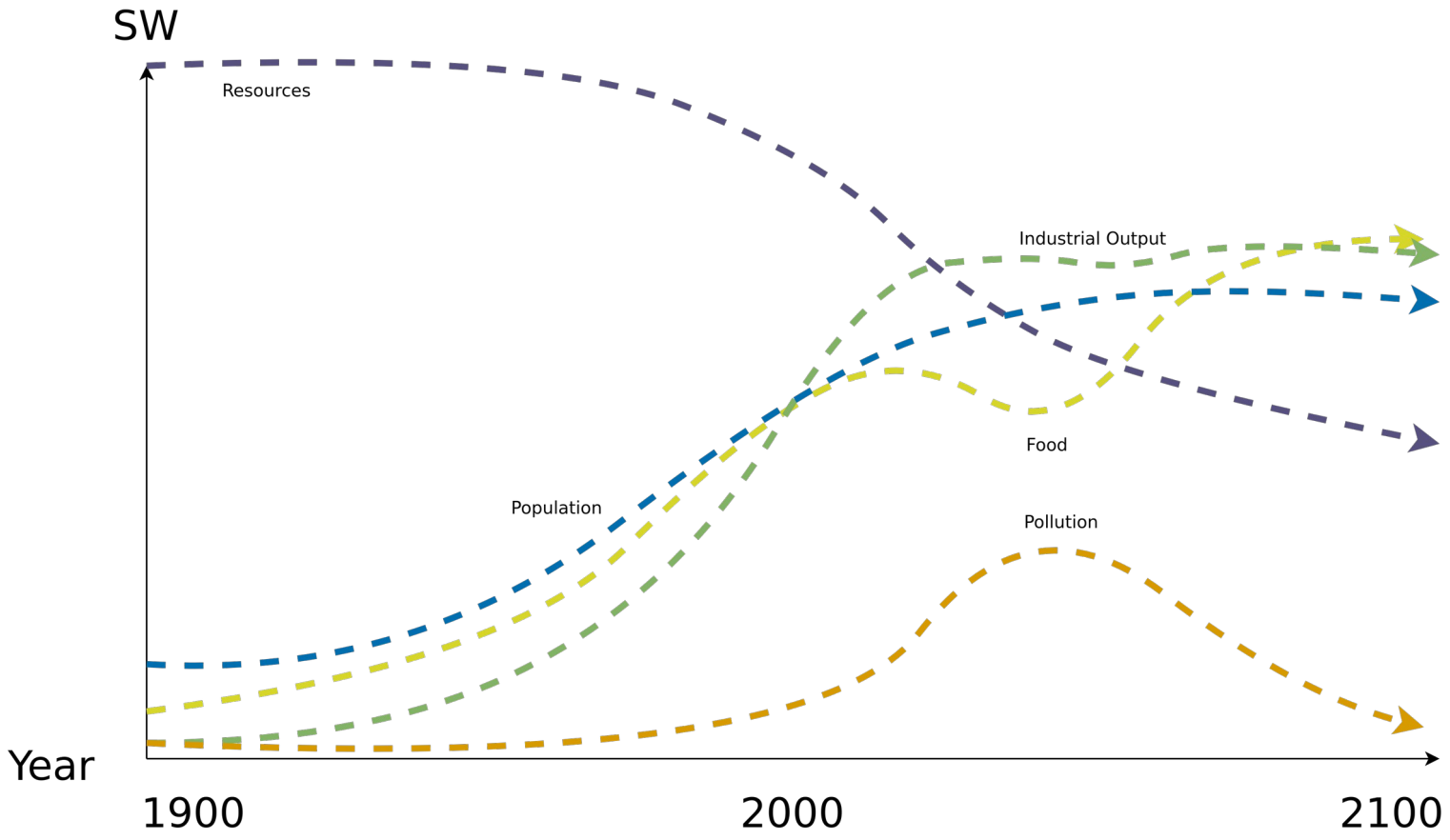
World3

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

Stabilized World (SW)



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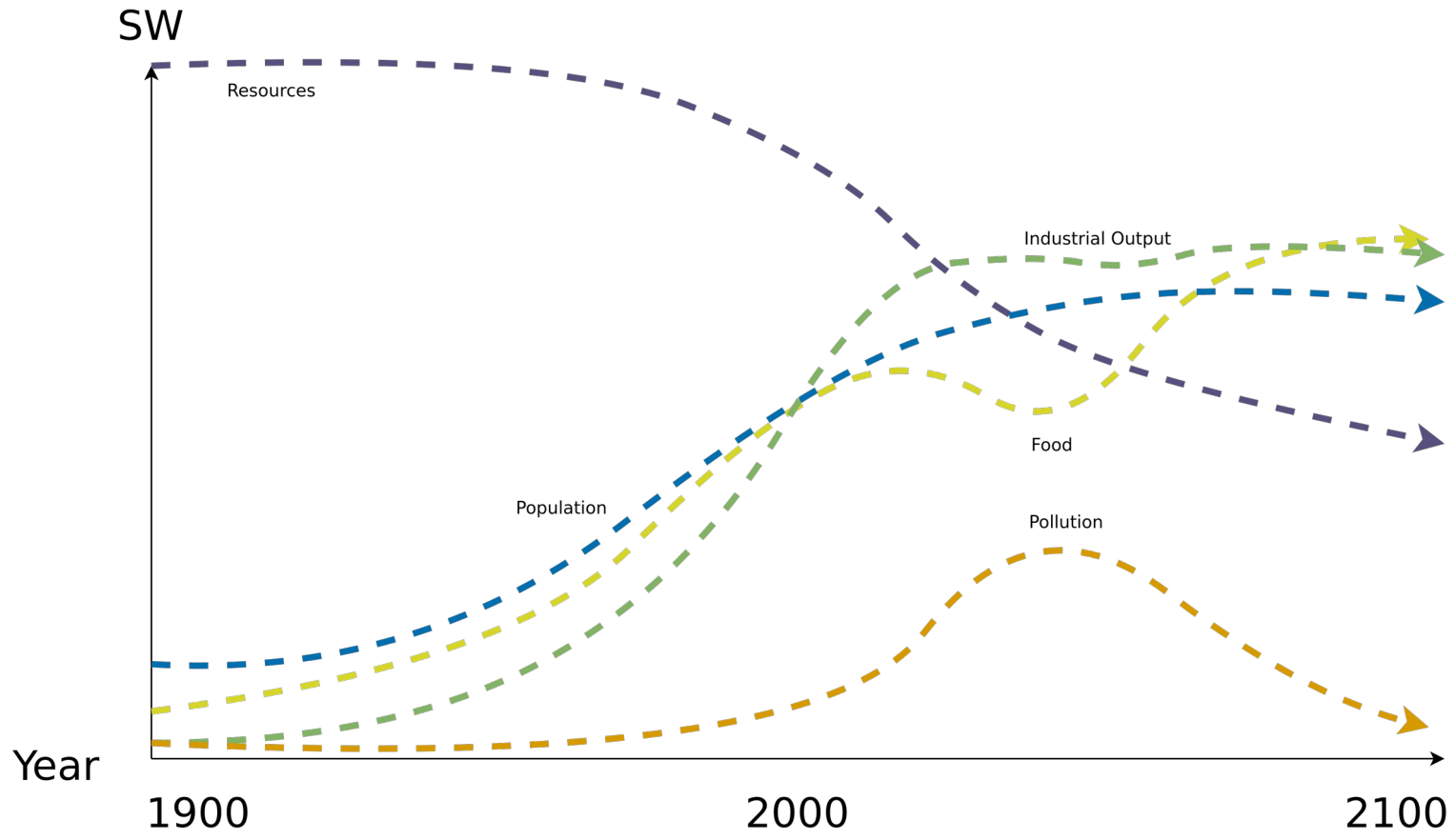
World3

Stabilized World (SW)



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

Image recreated from: Gaya Herrington (2020) – Update to limits to growth: Comparing the World3 model with empirical data – Link

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 Wolrd (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

F. E. Cellier (2008) – World3 in Modelica: Creating System Dynamics Models in the Modelica Framework – Link

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

Brian Hayes (2012) – Computation and the Human Condition (Harvard SEAS) – Link

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

EXERCISE E04

Exercise E04

World3

- Have a look at the 4 World3 scenarios that we discussed in the lecture (BAU, BAU2, CT, SW) → Note: Have a look at the links to World3 web version and play around with the model and learn about it in more detail.
- What actions (which policies) could we (humans/politicians) act upon to move the simulation results of the World3 model towards the SW scenario.
- Identify **3 proposals** and describe each of them in 3 or more sentences.
- Submit the exercise according to the instructions in the exercise sheet.

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
- Brian Hayes (2012) – Computation and the Human Condition (Harvard SEAS) – Link

Questions?