The Limits to Growth: Sustainability and the Circular Economy

Lecture 5: Limits to Growth and Planetary Boundaries

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- Updated versions of these slides will be available in our Github repository.

NEWS/UPDATES

News/Updates

Lecture Plan – Update

Date	Lecture Title
30.10.2024	L00 – Organisation L01 – Introduction
06.11.2024	L02 – Challenges I – Climate Change
13.11.2024	L03 – Challenges II – Environmental Pollution and Resources
20.11.2024	L04 – A History of Political (In-) Action **(Flipped Classroom → MOOC@Home + Live Lecture)**
27.12.2024	L05 – Overshoot, the Limits to Growth and Planetary Boundaries
04.12.2024	L06 – LifeCycle Assessment (LCA) **(Flipped Classroom → MOOC@Home + Live Lecture)**
11.12.2024	L07 – Ethics and Morals of Sustainability
18.12.2024	L08 – Circular Economy **(Flipped Classroom → MOOC@Home + Live Lecture)**
08.01.2025	L09 – Circular Societies **(MOOC)**
15.01.2025	L10 – Beyond the Circular Economy I
22.01.2025	**L11 – Invited Lecture (Gabriel from the CatFarm project) - Power in Balance: Horizontal Governance for Collaborative Communities**
29.01.2025	L12 – Beyond the Circular Economy II
05.02.2025	L13 – Complex Societies and Technology L14 – Summary

News/Updates

E02 – Resource Scarcity

- Goal: Investigating and tackling the challenges of shared resource management. Use Case → Fishing in the Atlantic Ocean.

- Key concepts:
  - Overexploitation – over use of common resource leads to its depletion
  - Individual vs. Collective benefits – one’s own interest or group welfare
  - Sustainability – management and preservation strategies
  - Regulation and Cooperation – prevent tragedy

News/Updates

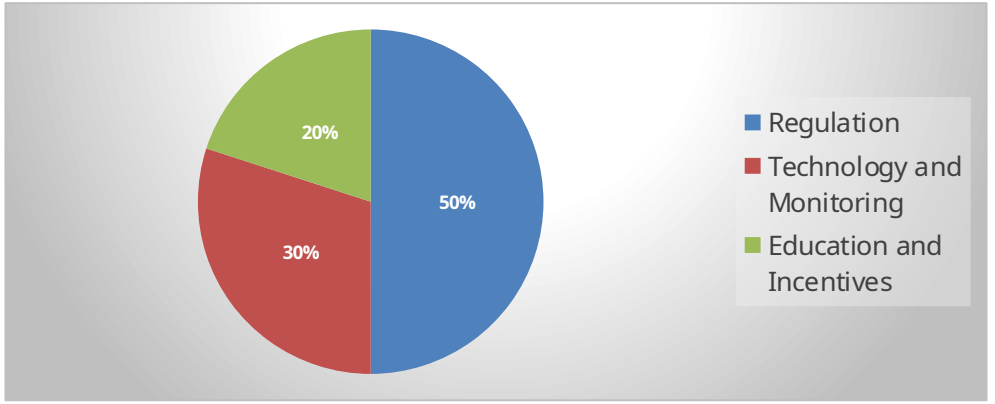
E02 – Resource Scarcity

- Recurrent suggestions on how to address the challenges posed by the game, categorized:

News/Updates

E02 – Resource Scarcity

- Recurrent suggestions on how to address the challenges posed by the game, categorized:
  - Regulation:
    - Fishing quotas
    - Special protected areas
    - Licence mechanisms
    - Seasonal restrictions
    - Taxes and monetary benefits



News/Updates

E02 – Resource Scarcity

- Recurrent suggestions on how to address the challenges posed by the game, categorized:
  - Regulation:
    - Fishing quotas
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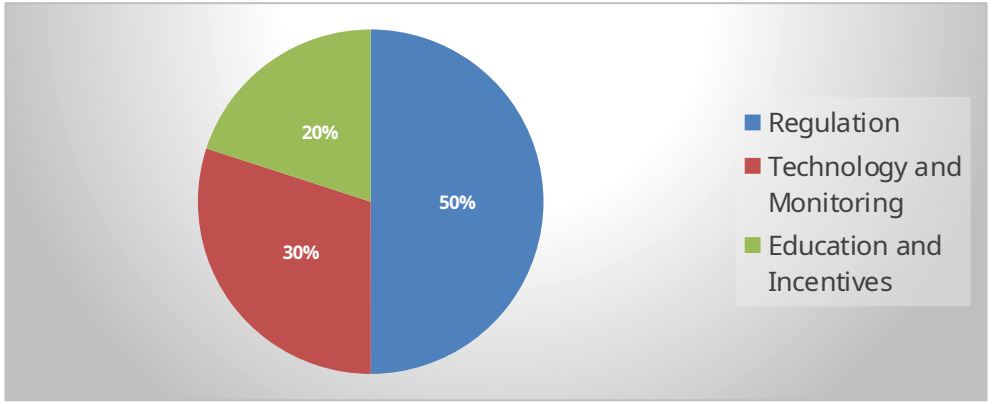
  - Monitoring and Technology:
    - Ocean police
    - Fish population tracking in real-time, e.g., satellite tracking
    - Predictive technology to calculate recovery rates of fish population



News/Updates

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  - Monitoring and Technology:
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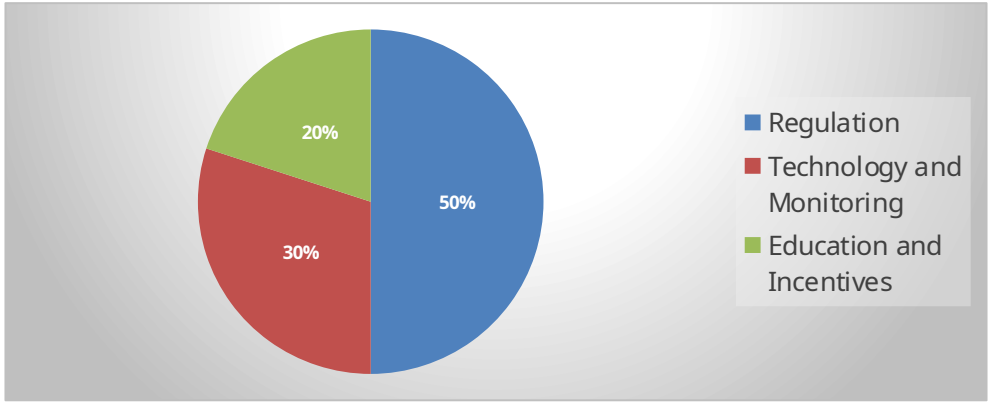
    - Fish population tracking in real-time, e.g., satellite tracking
    - Predictive technology to calculate recovery rates of fish population
  - Education and Incentives:
    - Encouraging sustainable practices
    - Fishing cooperatives



News/Updates

E02 – Resource Scarcity

Global regulatory bodies	• Ineffectiveness of UN sanctions brings in the need for a global organization that oversees sustainable fishing and establishing tax incentives.
Cooperative agreements among countries	• Countries work together to establish fishing cooperatives and implement sustainable fishing methods in shared waters.
Science-Based Recovery Rates	• Establish fishing activities restriction based on scientific data and the natural replenishment rate of species.
Overcoming greed	• Establish cultural shift in fishing communities or just prohibit fishing at a certain point.

News/Updates

E02 – Resource Scarcity

- Some challenges were observed:
  - Enforcing laws or sanctions in international waters can be problematic due to economic and political interests (UN failed).
  - Financial motivations behind overfishing as some people will make less profits since they usually fish the most/fastest.
  - Absence of international collaboration as not all countries agree to the same sustainable fishing practices.

News/Updates

E03 – Environmental Pollution (Follow-Up E01)

Avoidable purchases

- Used plastic bags even though had a reusable cloth bad
- Could have avoided buying chocolate bars that is wrapped in plastic
- Bought plastic packaged goods from the supermarket instead of at the bakery

Reusable items

- Glass jar from pasta sauce could have been cleaned and used for spices storage
- PET bottles could be reused as vases for flowers
- Repurposed a “mini snack salami” package into storage container

Supply Chain redesign

- Producers could switch to reusable glass containers that customers can return for recycling
- Replace single-use plastic packaging with biodegradable materials
- Add refill stations for products like shampoos to reduce packaging waste

News/Updates

E03 – Environmental Pollution (Follow-Up E01)

- Further proposals:
  - Switching to refill stations for products like rice, perfume.
  - Using leftover toast to create croutons or French toast.
  - Removing unnecessary packaging like sealing individual fruits or vegetables in plastic.
  - Make coffee at home to avoid the selling of coffee to-go cups.

INTRODUCTION

Introduction

Finite Systems – Sandbox / Playground

Introduction

Earth Overshoot Day

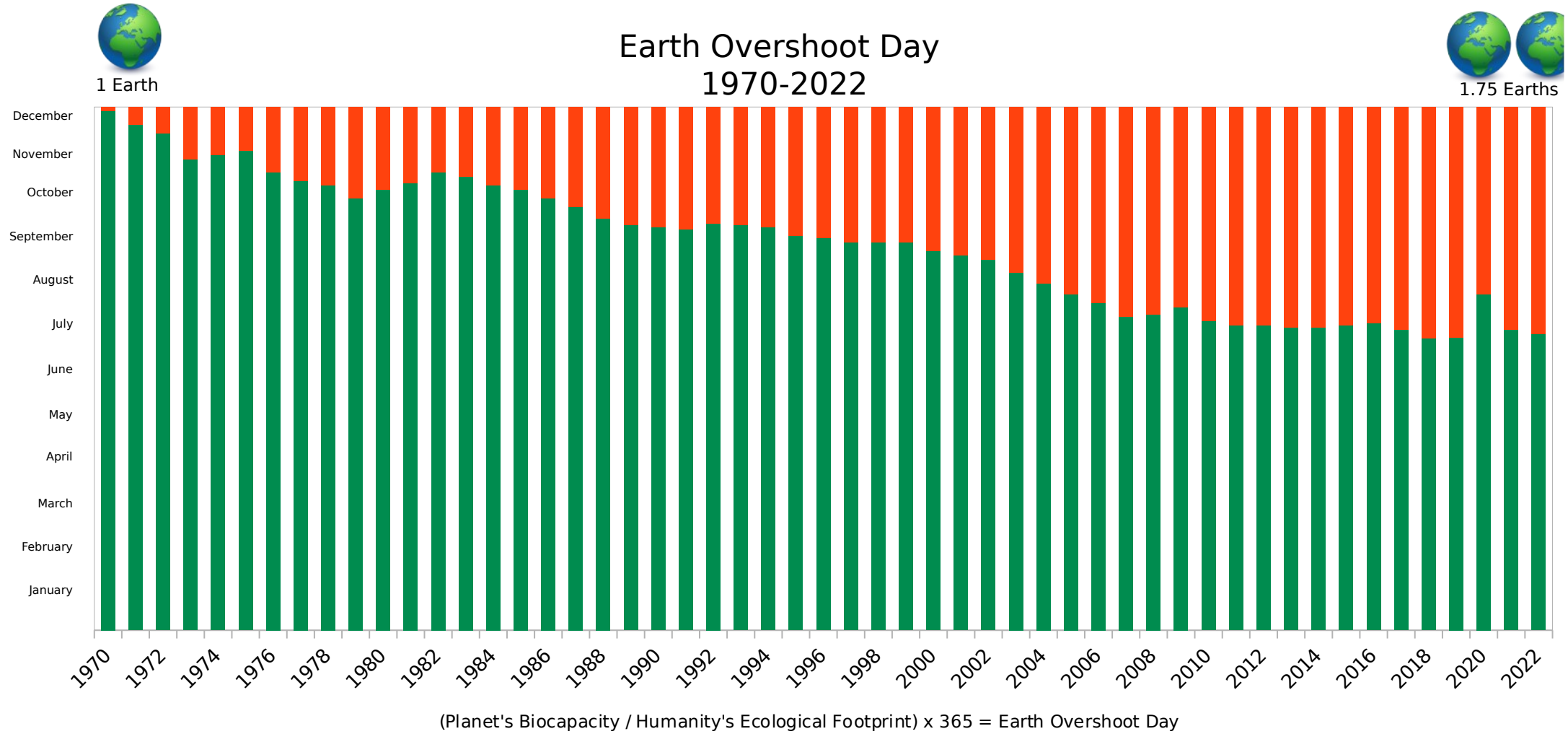


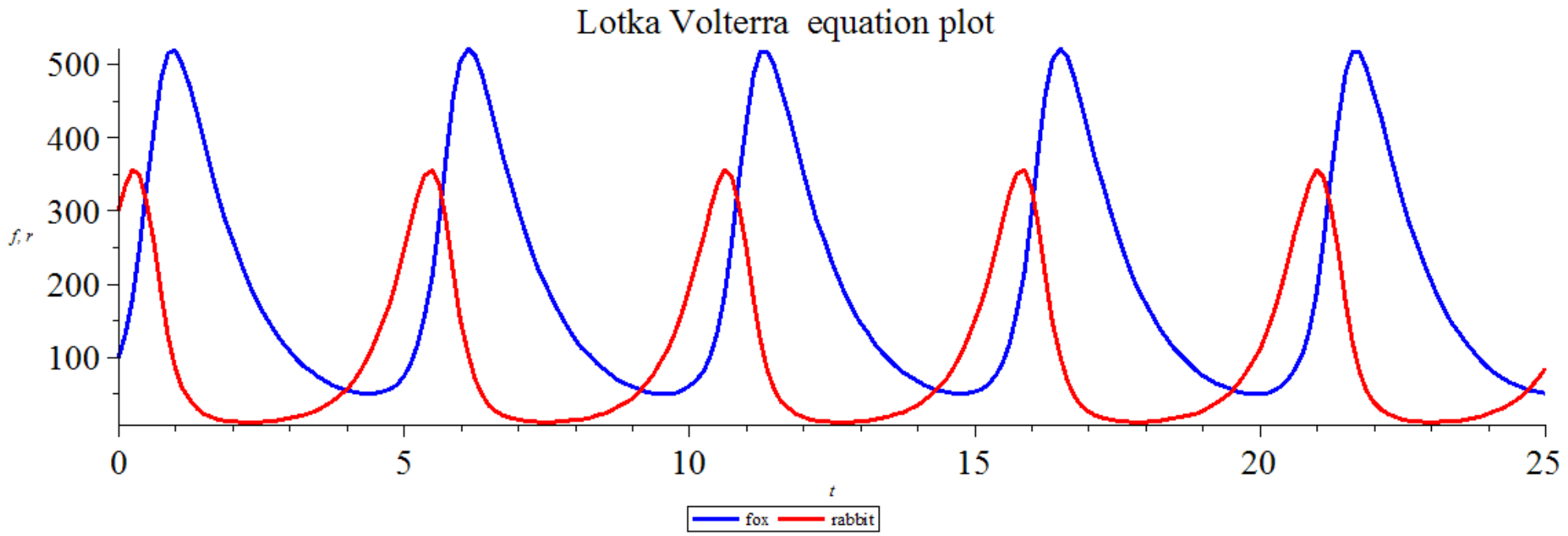
Figure adapted from https://www.overshootday.org/newsroom/past-earth-overshoot-days/

Introduction

Lotka–Volterra Equations (Predator–Prey Equations)

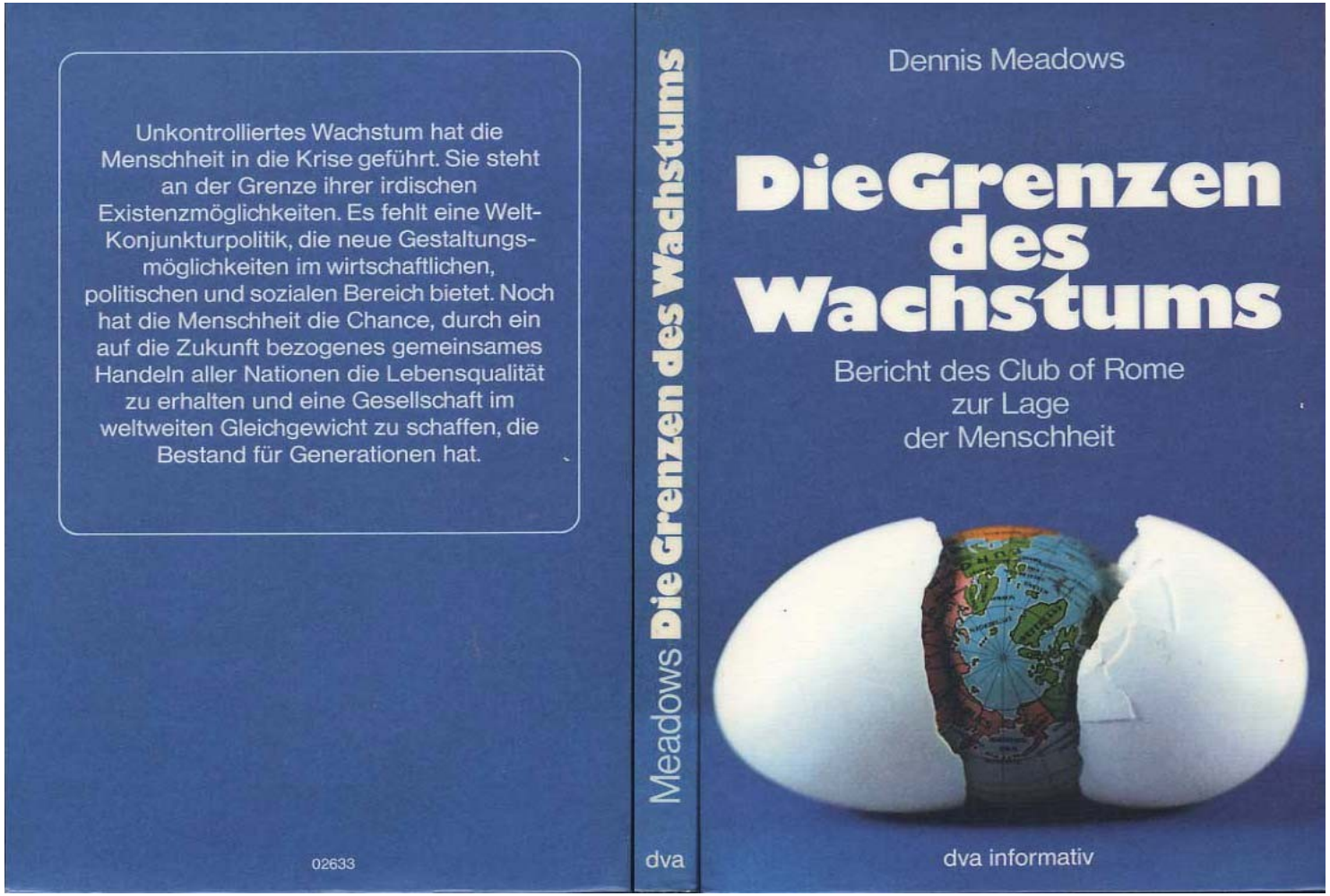
Introduction

Lotka–Volterra Equations (Predator–Prey Equations)



Introduction

The Limits to Growth – 1972



Introduction
The Limits to Growth

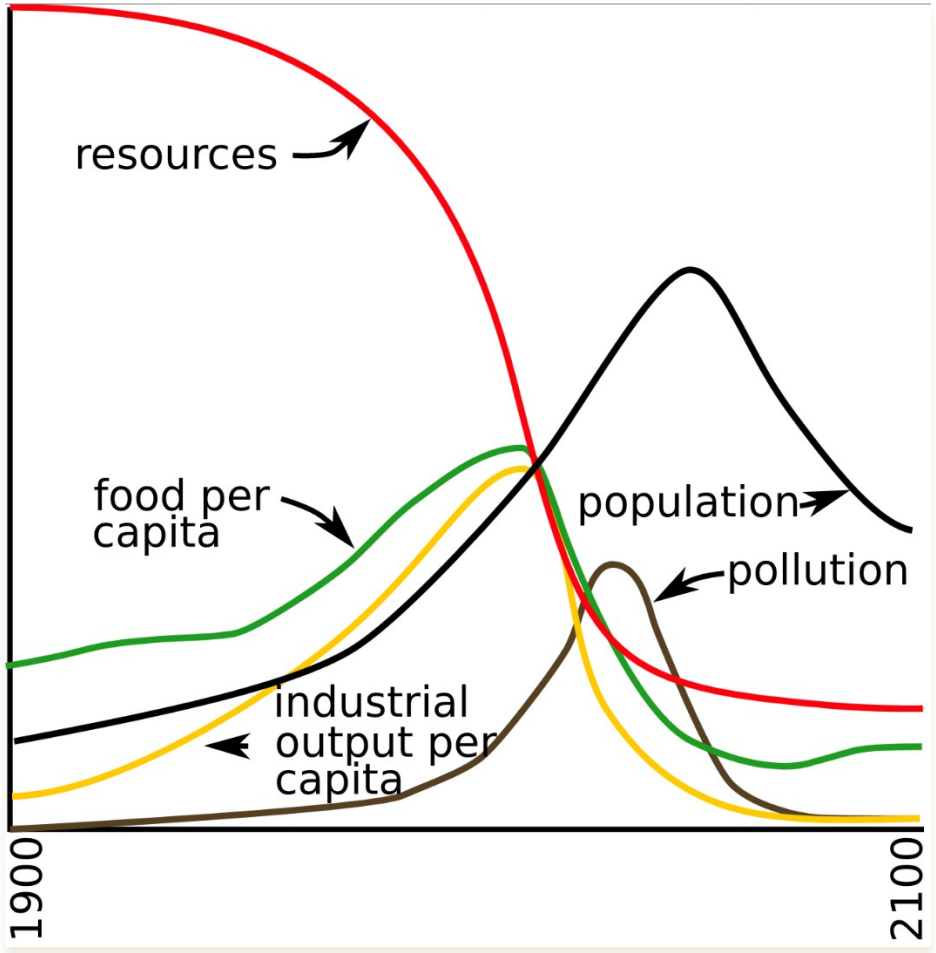
“If the present growth trends in world population, industrialization, pollution, food production, and resource depletion continue unchanged, ***the limits to growth on this planet will be reached sometime within the next one hundred years.***

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

Meadows (1972) – The Limits to Growth

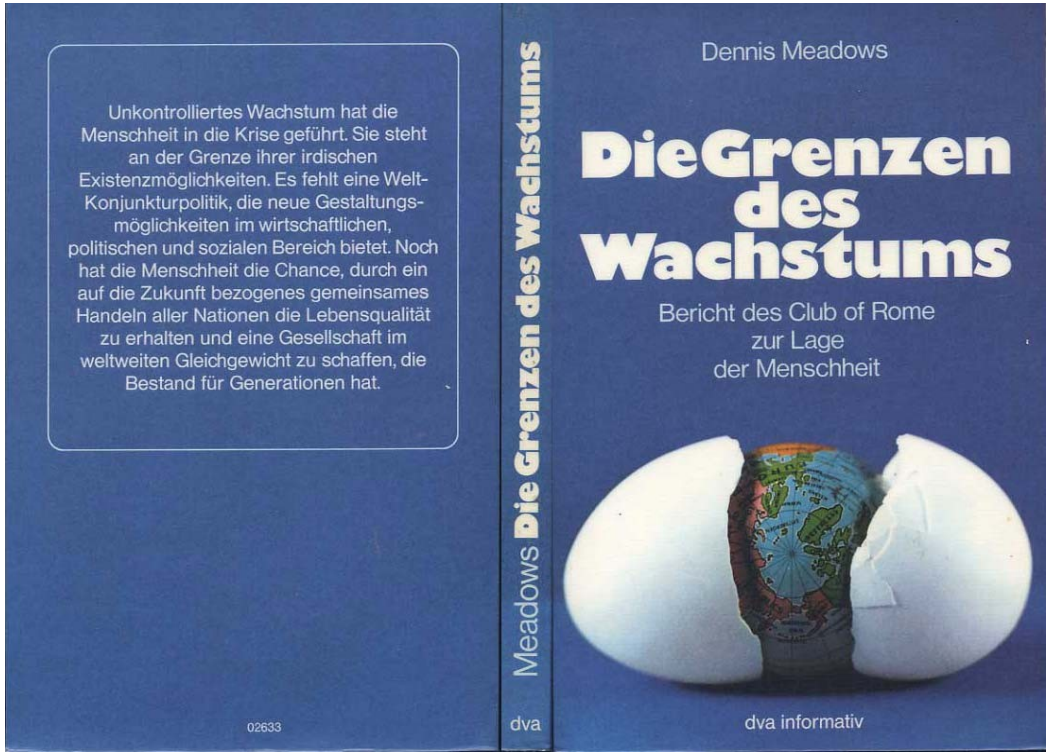
Introduction

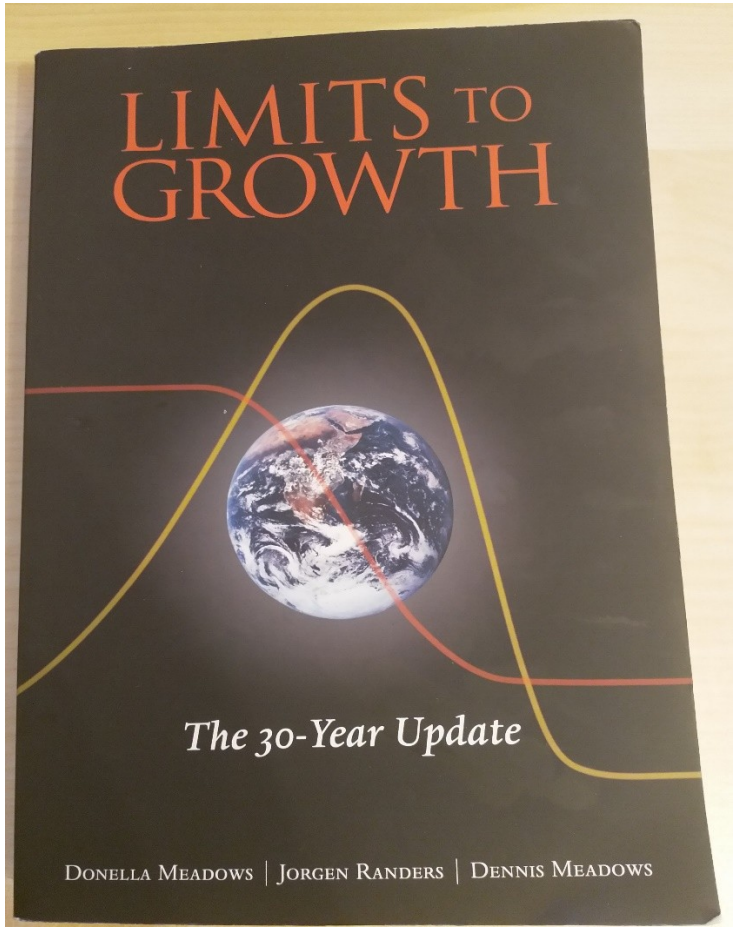
The Limits to Growth – World3 Standard Run



Introduction

The Limits to Growth – 1972 / 2004





Introduction

The Limits to Growth – World3 Model

Click Me

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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

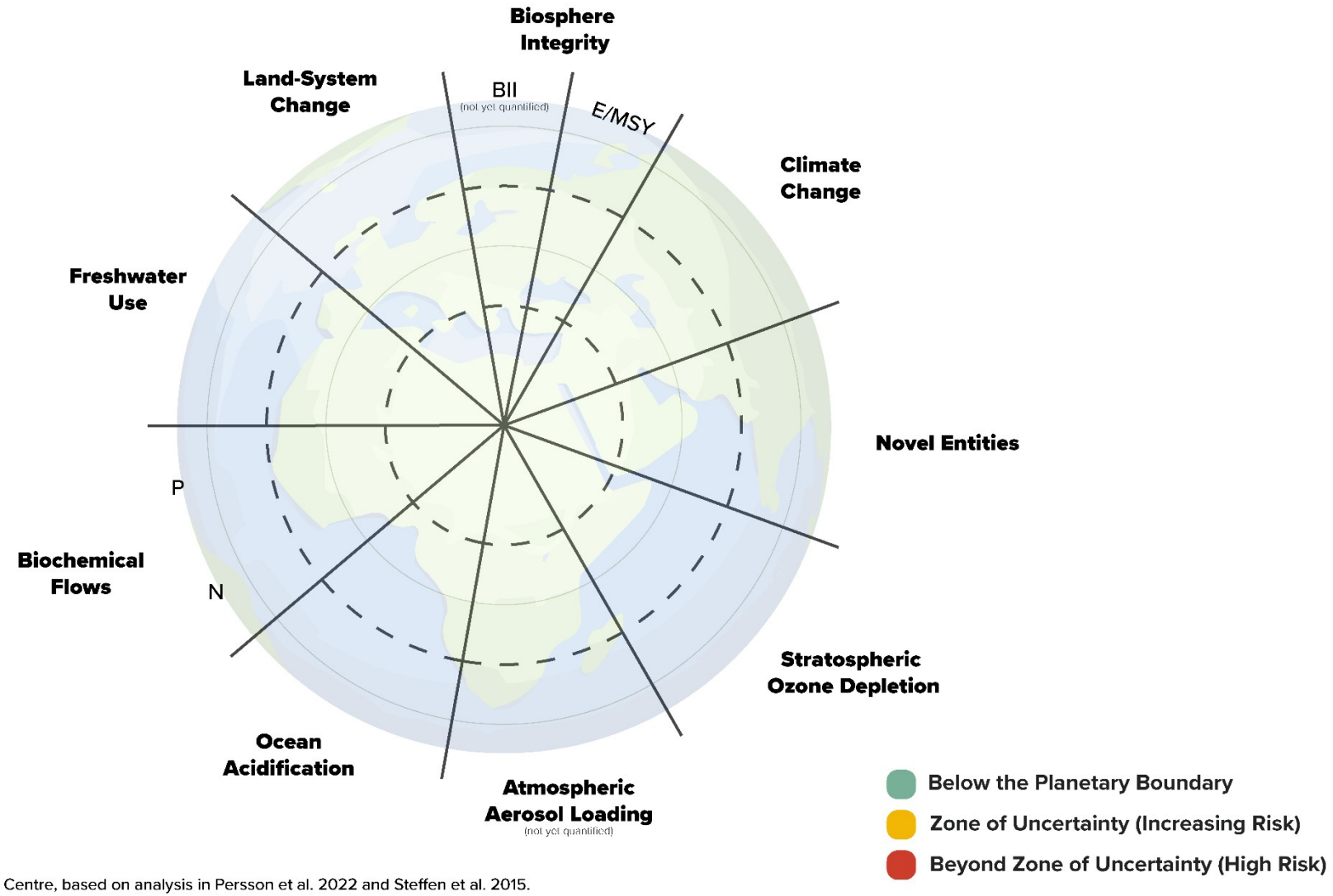
Planetary Boundaries

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

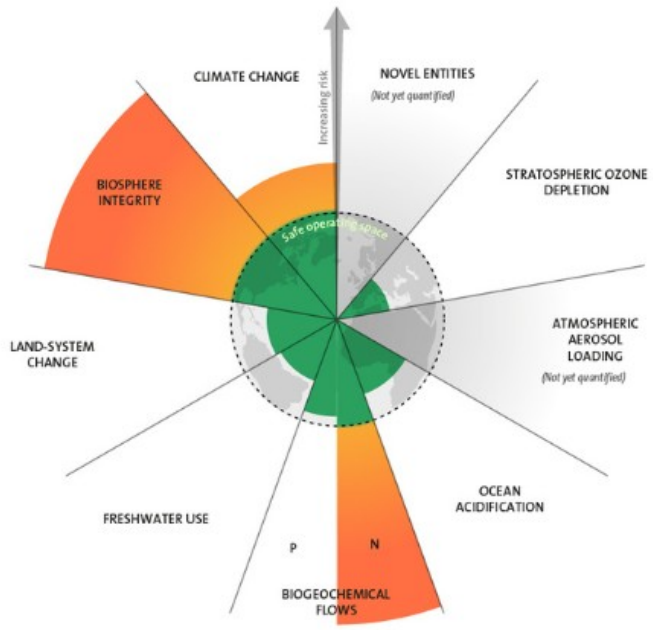
Concept



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

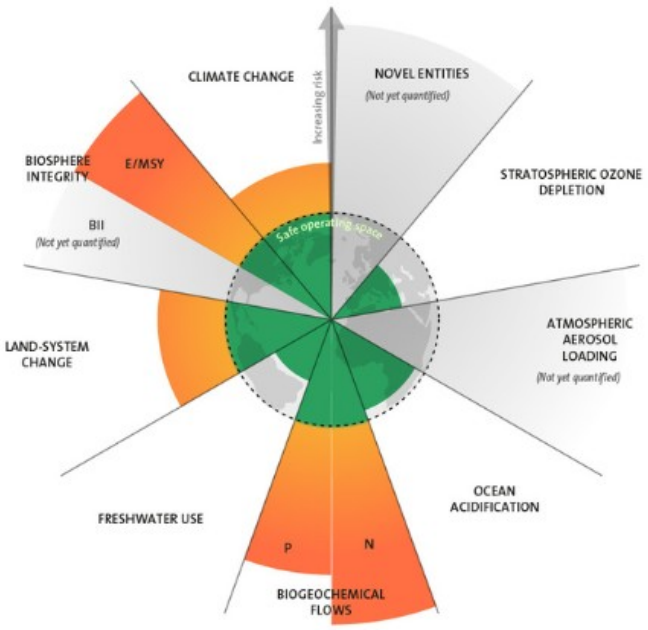
Planetary Boundaries

2009



7 boundaries assessed,
3 crossed

2015



7 boundaries assessed,
4 crossed

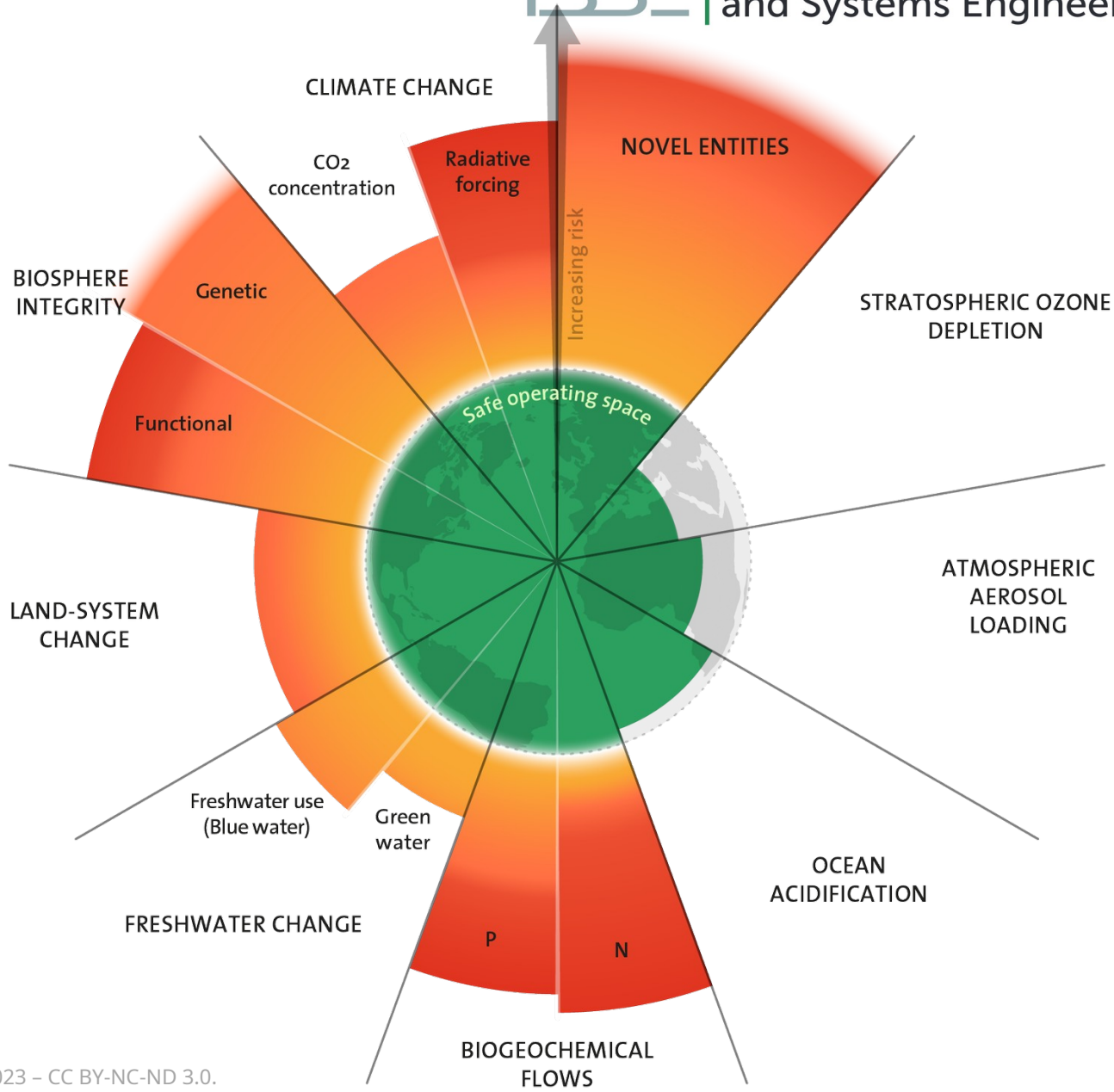
2023

9 boundaries assessed,
6 crossed

The evolution of the planetary boundaries framework. 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

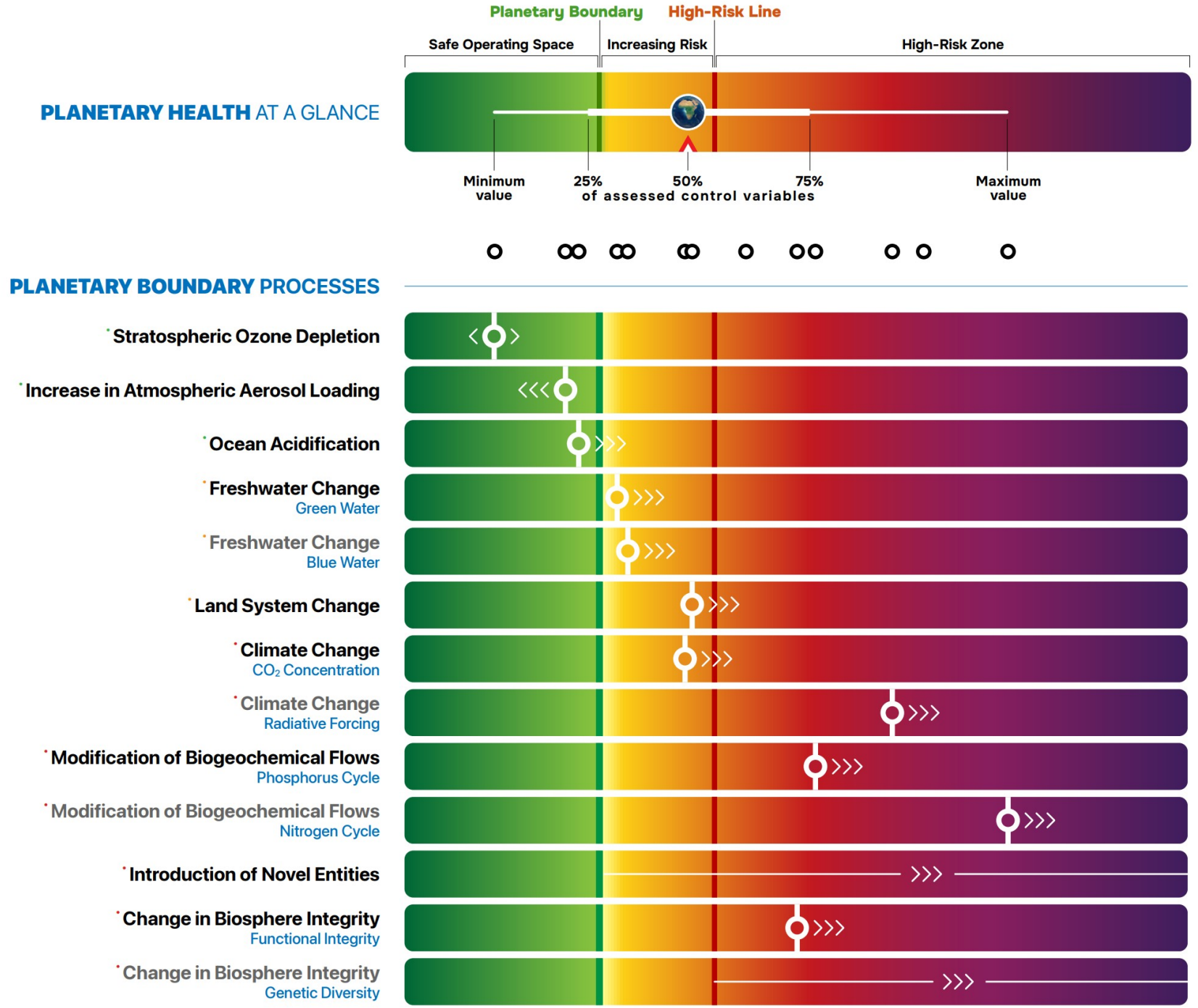
- All boundaries are finally assessed
- Six boundaries are now transgressed and pressure is increasing on all boundary processes → only exeption is the ozone depletion



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

TU Clausthal

Planetary Boundaries
2024



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

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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)

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World3

History – System Dynamics

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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)
- 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

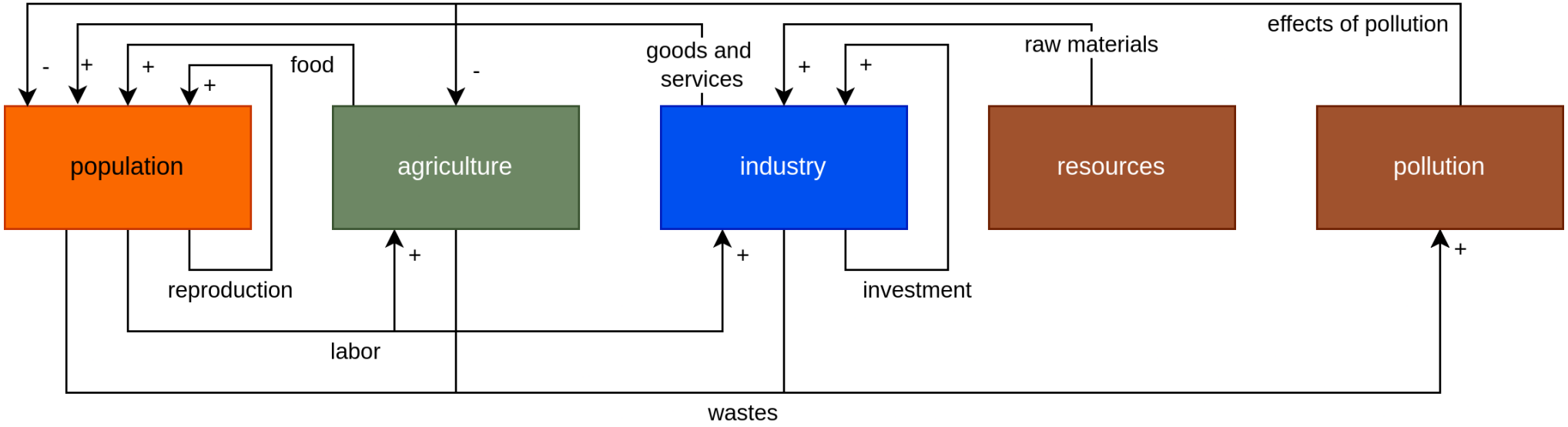


Image recreated from: Brian Hayes (2012) – Computation and the Human Predicament – Link

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

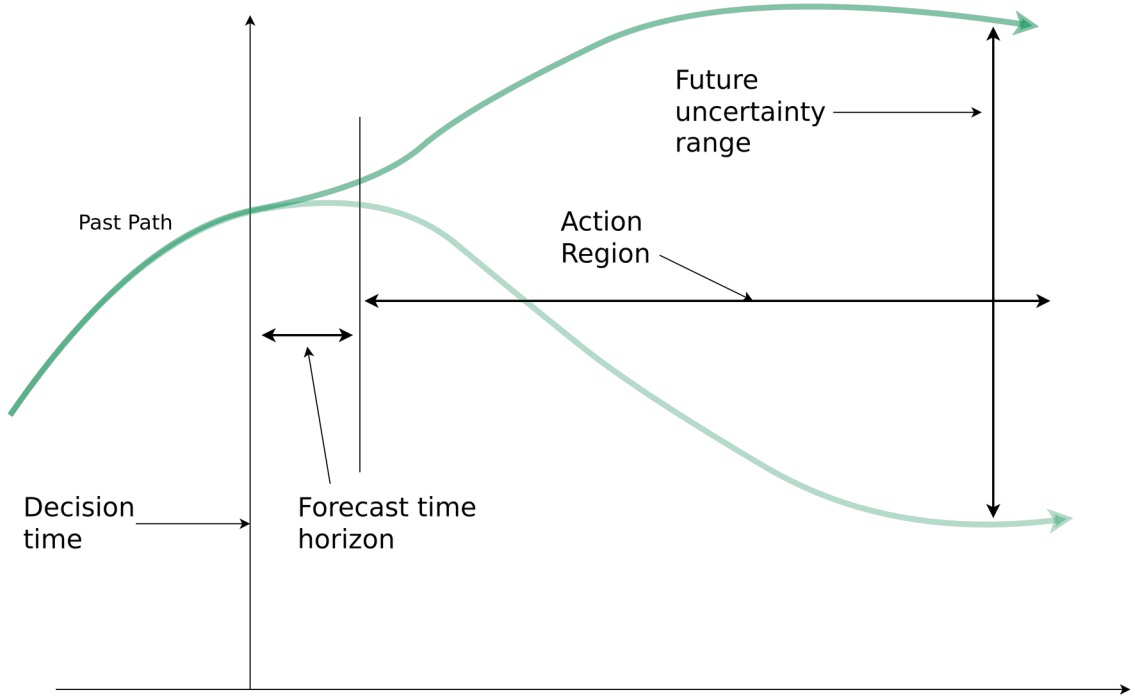
World3

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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World3

Simulation Results

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

World3

Simulation Results

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- 4 popular scenarios:
  - Business-as-usual (BAU)

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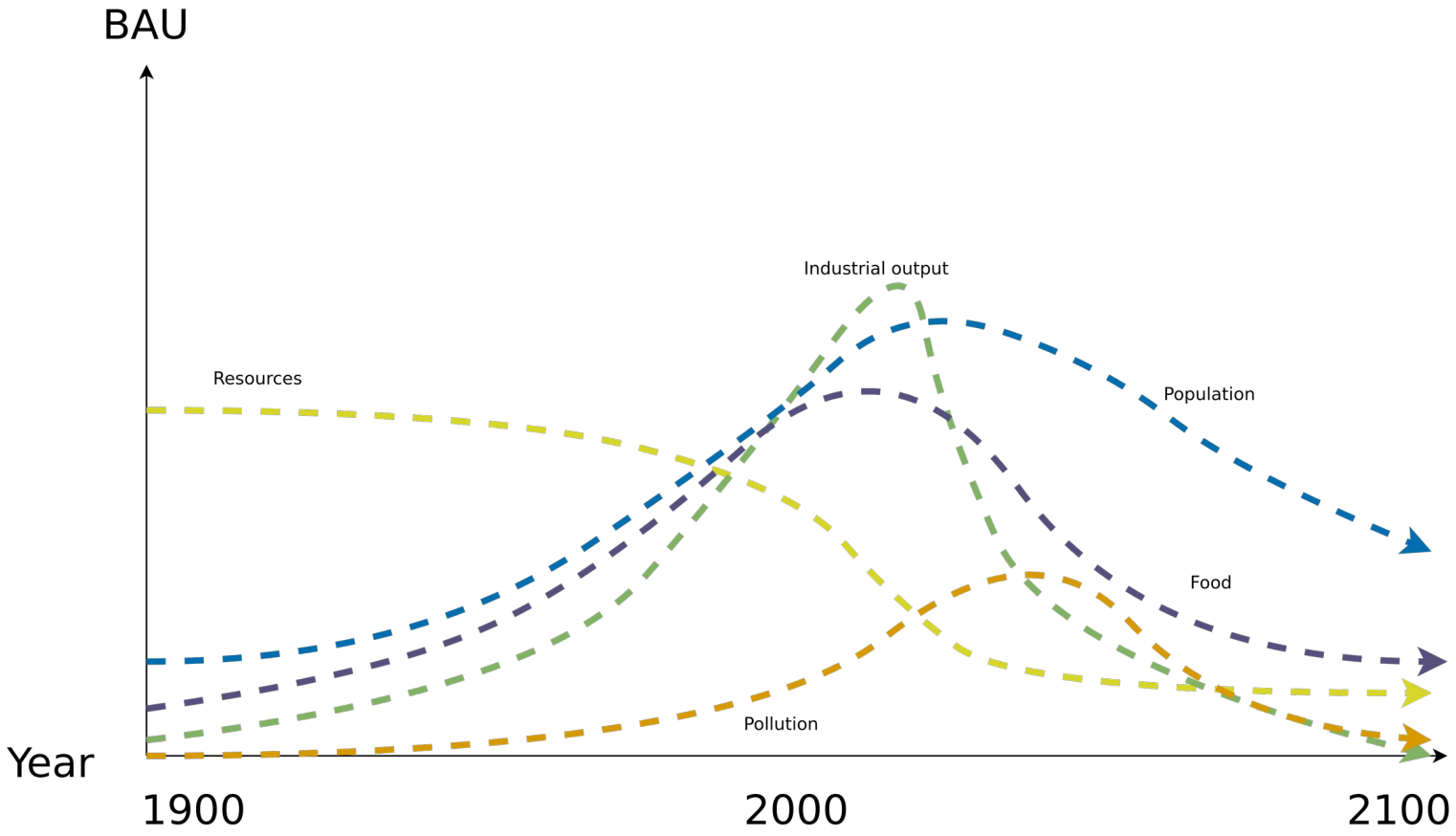
Standard Run – Business-as-Usual (BAU)



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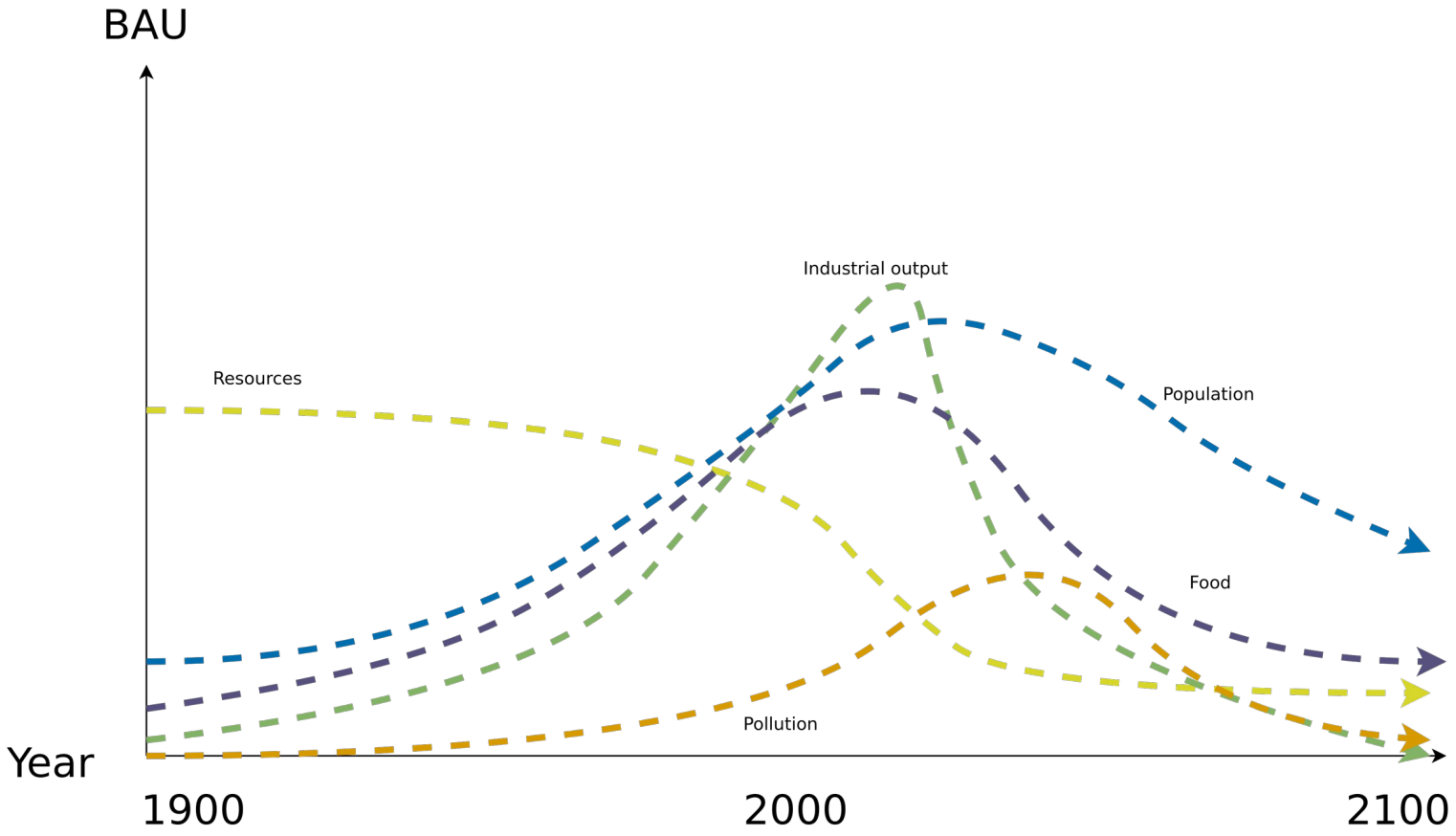
Standard Run – Business-as-Usual (BAU)



→ 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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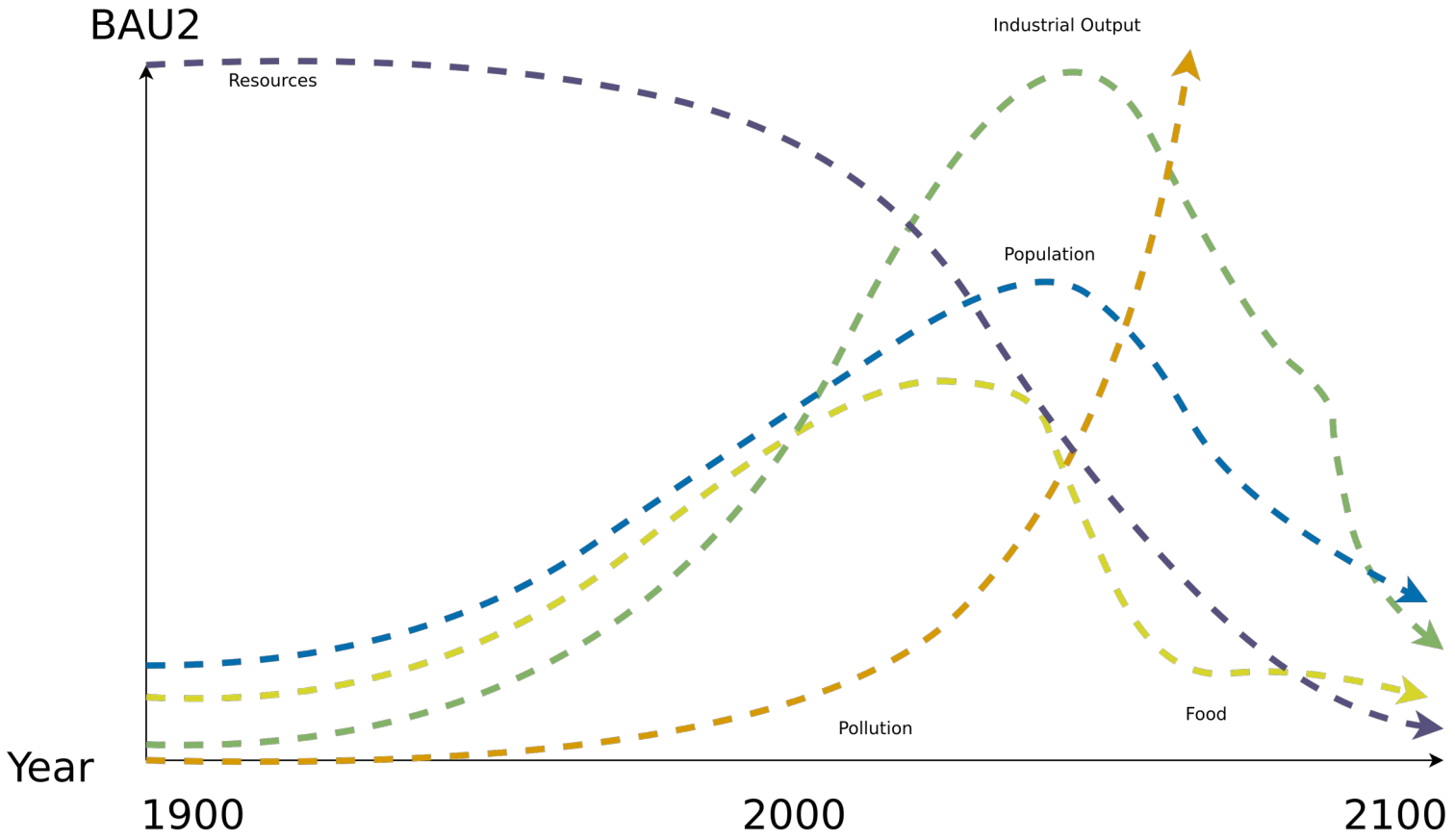
Standard Run – Business-as-Usual2 (BAU2)



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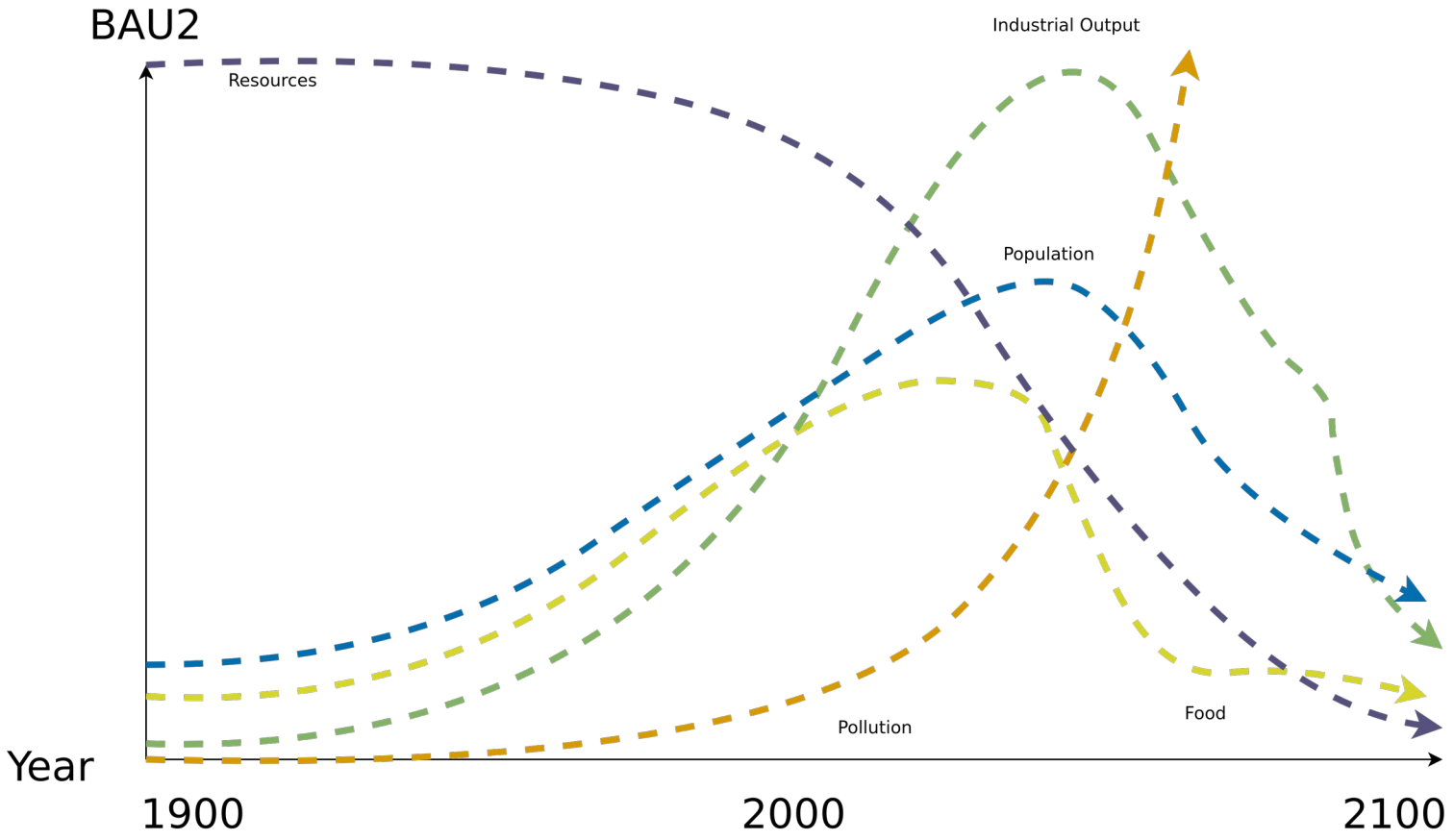
Standard Run – Business-as-Usual2 (BAU2)



→ Collapse due to pollution (climate change equivalent)

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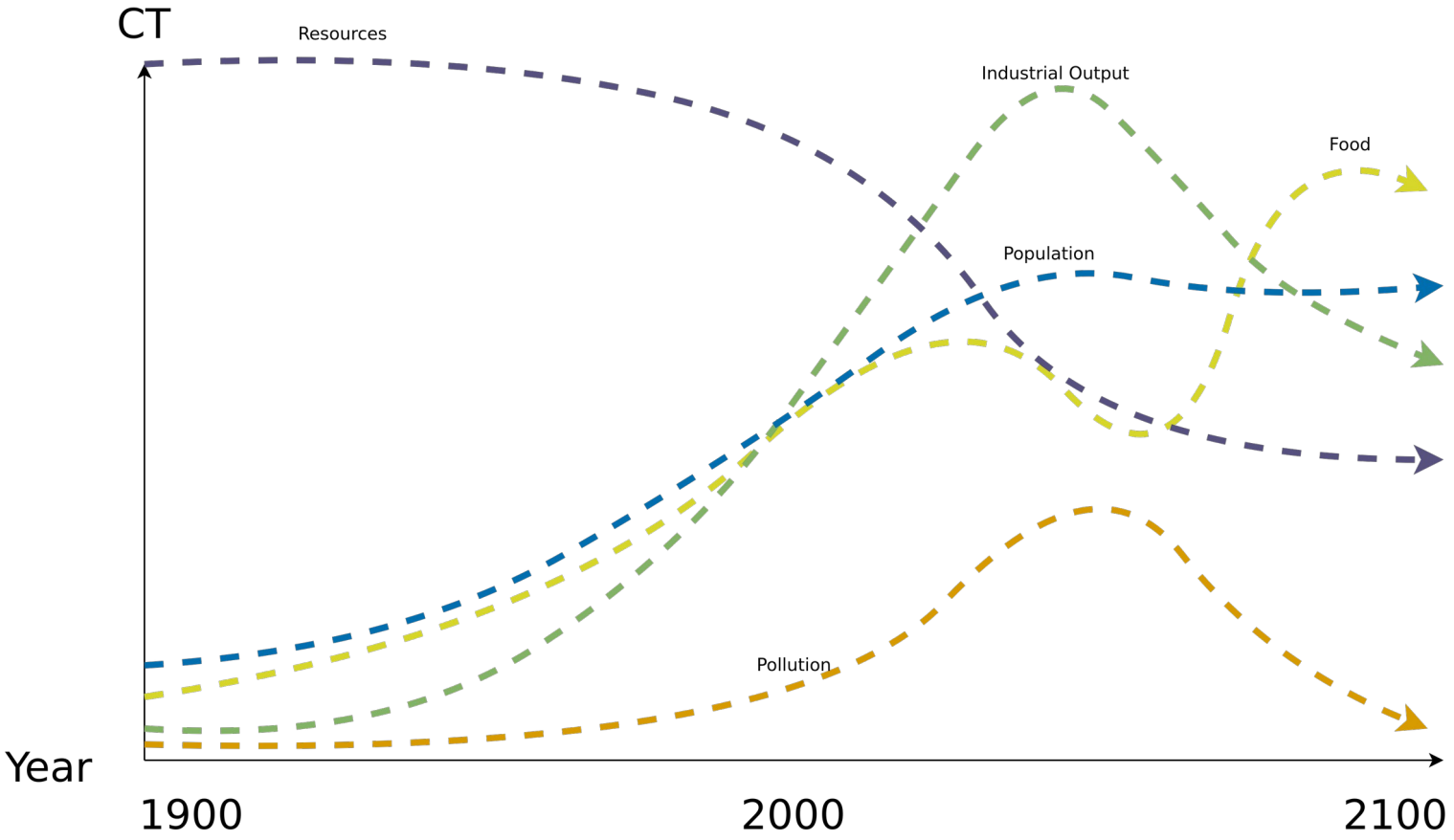
Simulation Results

- 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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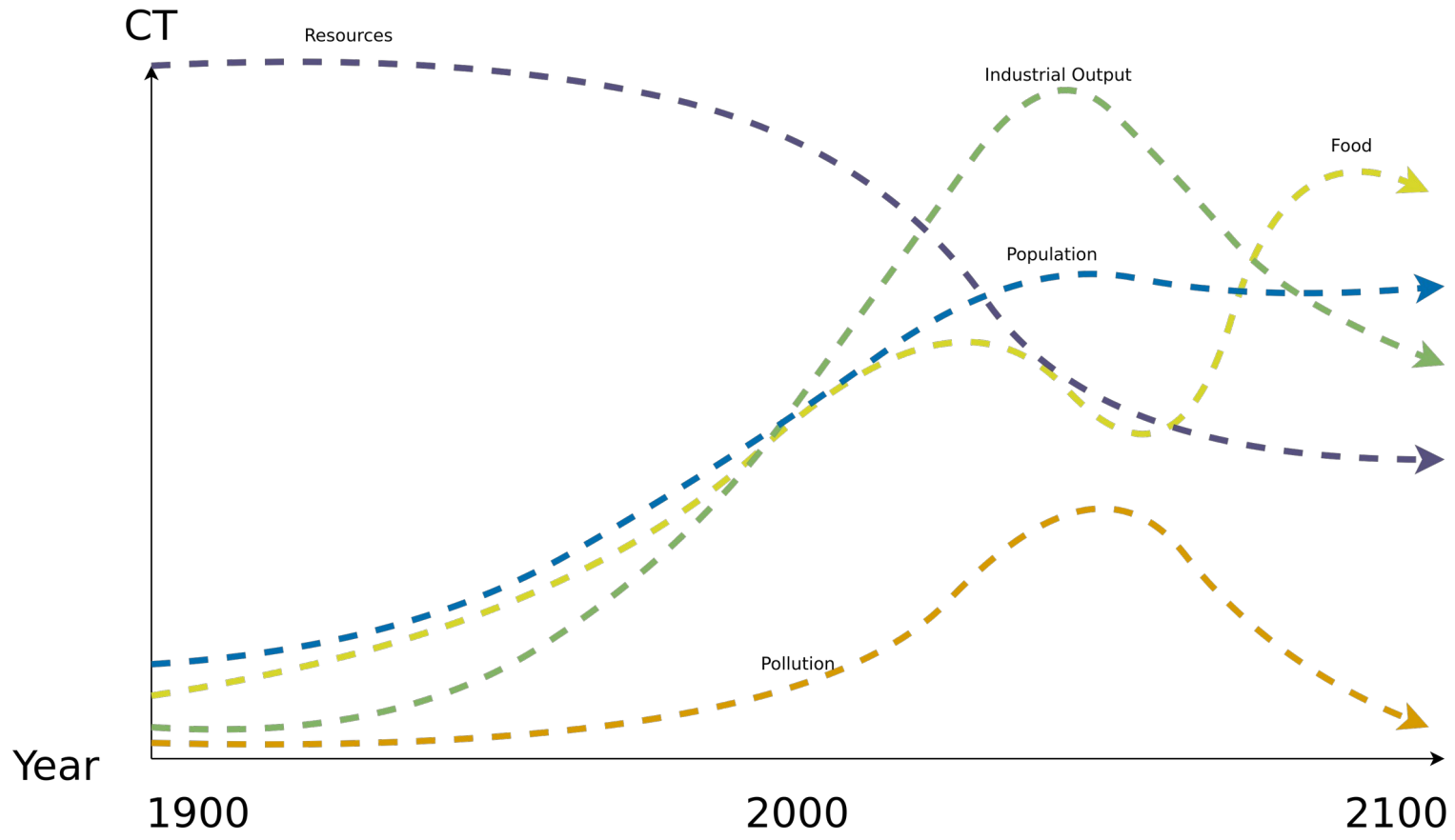
Comprehensive Technology (CT)



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

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World3

Simulation Results

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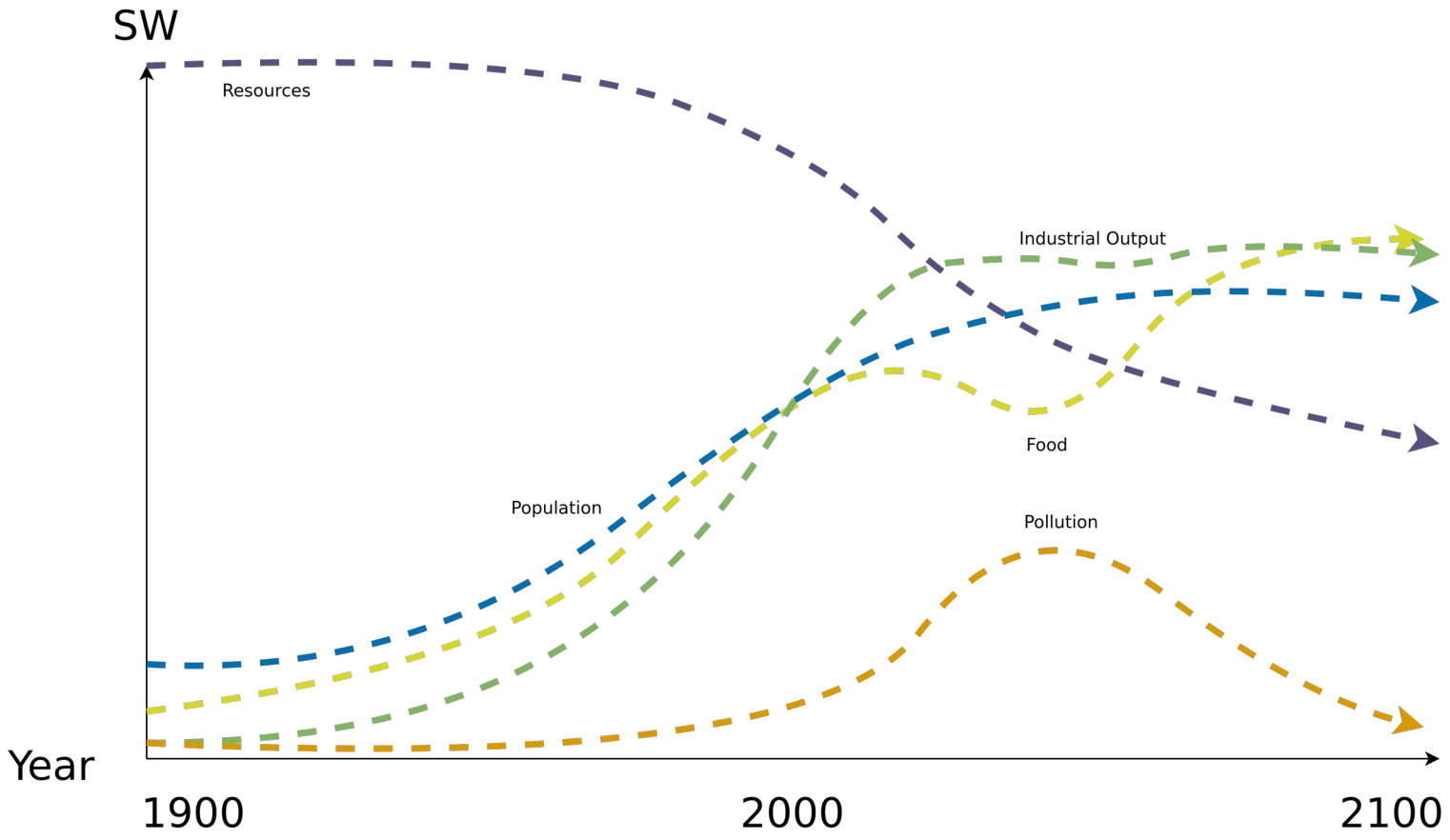
  - Business-as-usual (BAU)
  - Business-as-usual2 (BAU2) → double the natural resources of BAU
  - Comprehensive Technology (CT) → BAU2 + exceptionally high technological development and adoption rates
  - Stabilized World (SW) → CT + changes in societal values and priorities

World3

Stabilized World (SW)



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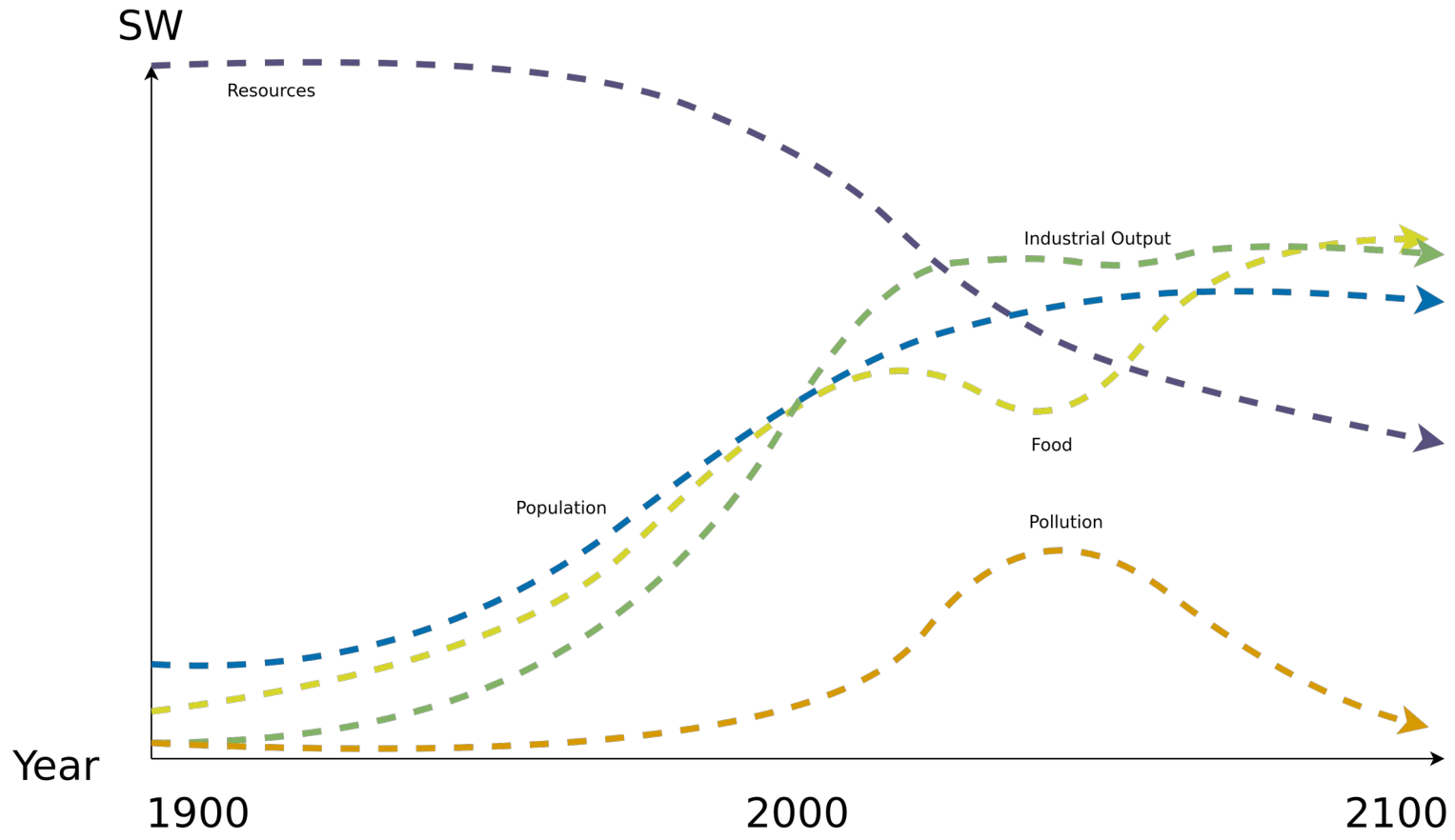
Stabilized World (SW)



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

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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

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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

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?