The Limits to Growth: Sustainability and the Circular Economy

Lecture 6: World3

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

NEWS

Examination Info
Clausthal and Göttingen

- Oral examination
- 15-20min Q&A
- Dates:
  - 11.08.2022
  - 12.08.2022

Examination Registration
Clausthal

1. Registration for the exam in the Studienportal (only one exam date visible → technical limitation)
2. Get in contact with us and request an examination time slot
3. Receive an examination timeslot
4. Write an email to the examination office (**put etce-ltg@tu-clausthal.de in CC**) and notify the examination office about the examination timeslot that you received from us.

Examination Registration
Göttingen

- Ähhhmmm …
  - Please talk to your examination office and ask them what needs to be done
  - Afterwards, drop us an email → etce-ltg@tu-clausthal.de

EXERCISE E03

Exercise E03 – Favorite Fruit/Vegetable
Feedback

- Many students provided a guide on "how to grow X" instead of the required resources
- Others really thought ahead, e.g. Mango: You first need to grow and care for a mango tree for several years before you can actually start harvesting

INTRODUCTION

Introduction
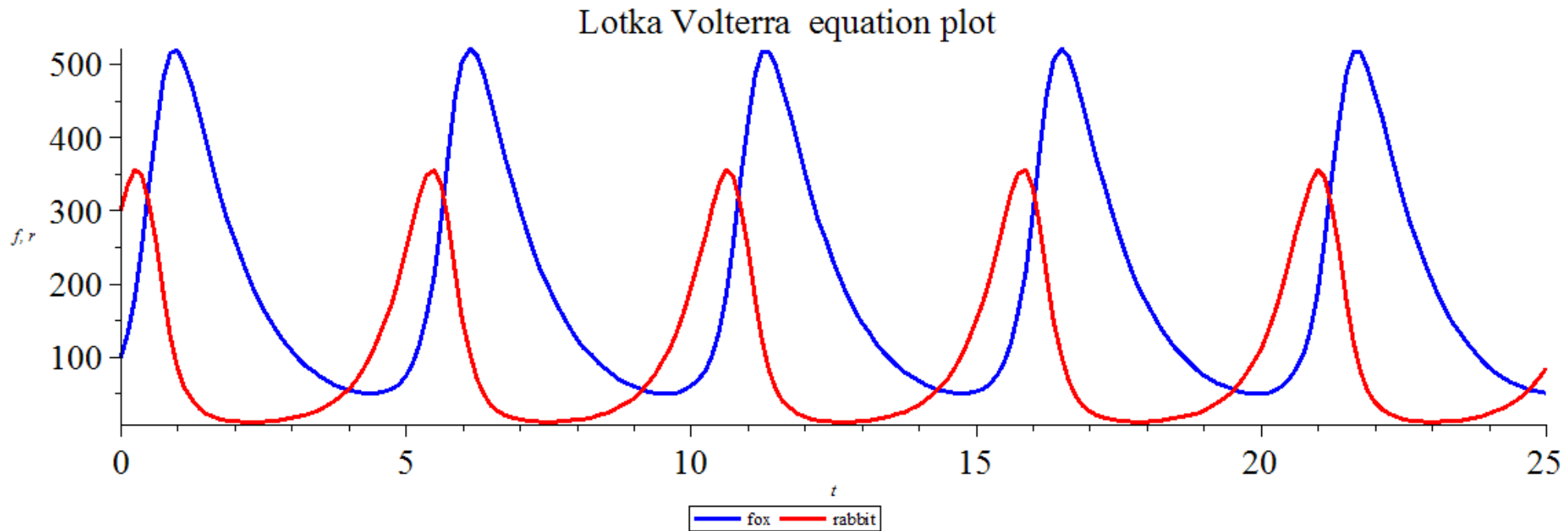
Finite Systems – Sandbox / Playground

Introduction

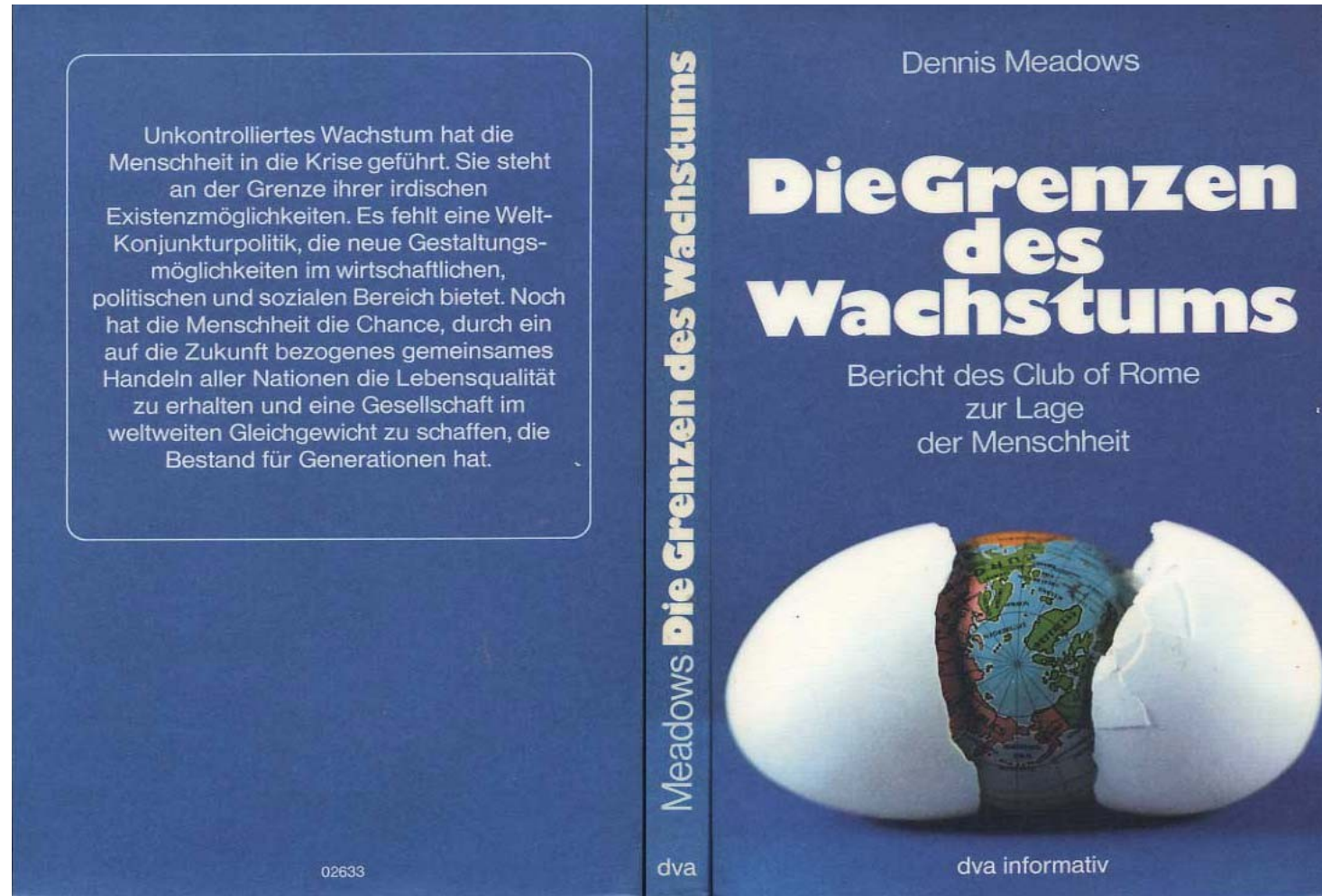**Lotka–Volterra Equations (Predator–Prey Equations)**

Introduction

Lotka–Volterra Equations (Predator–Prey Equations)

Lotka Volterra equation plot

Introduction
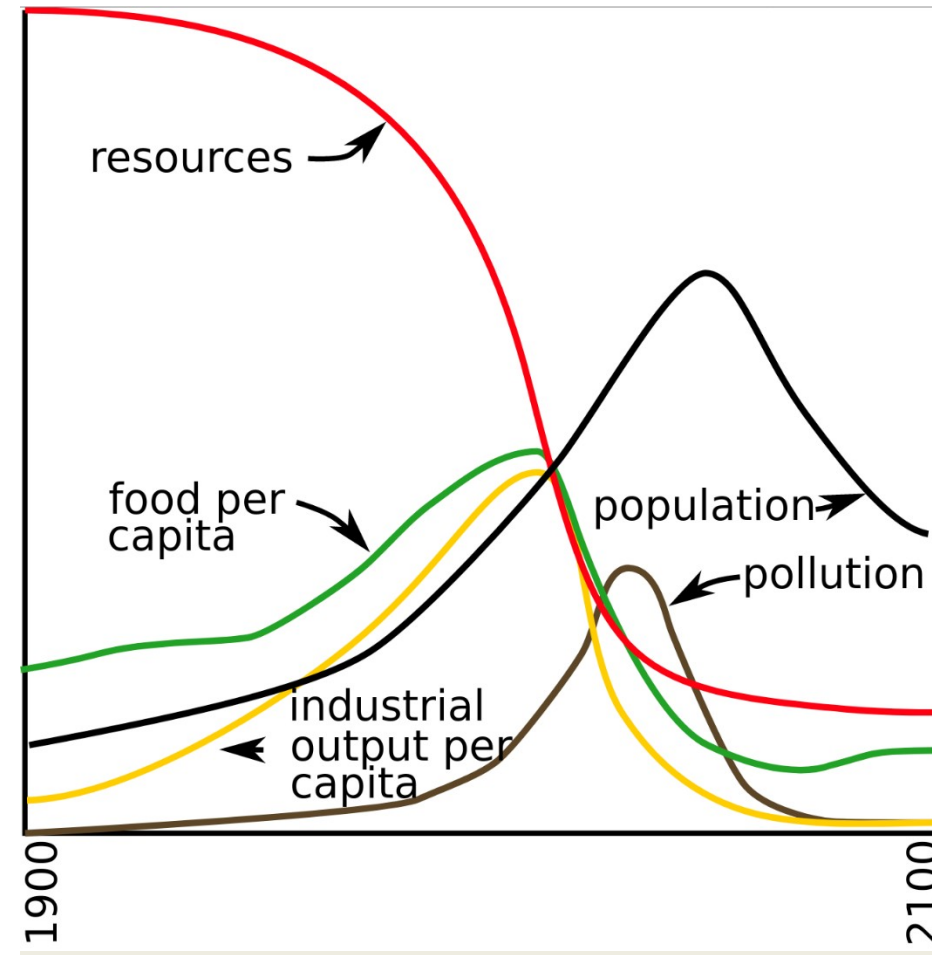
The Limits to Growth – 1972

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.**"
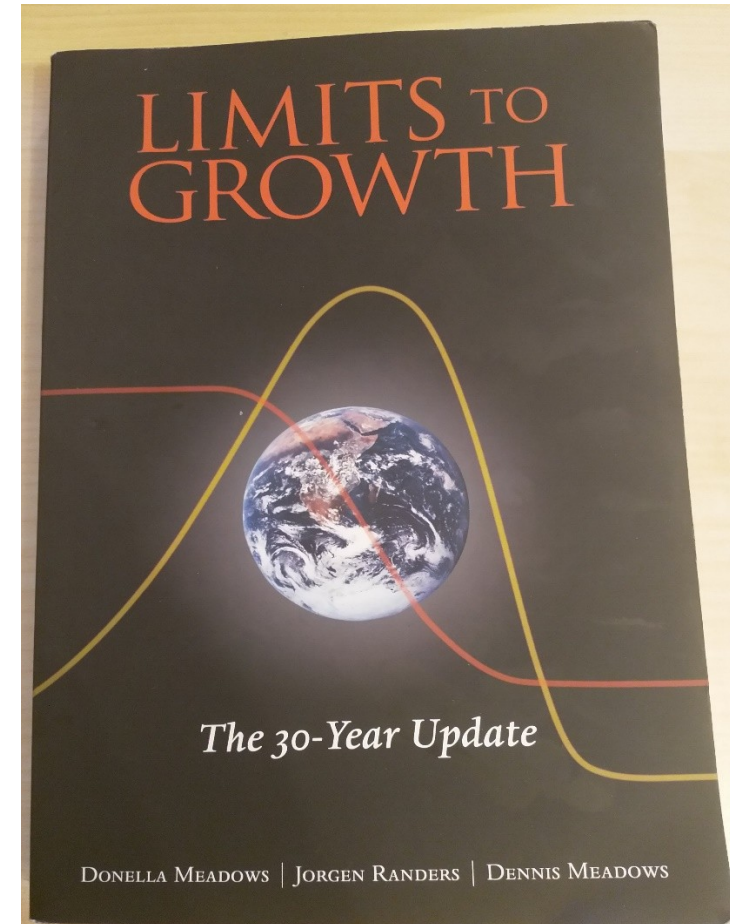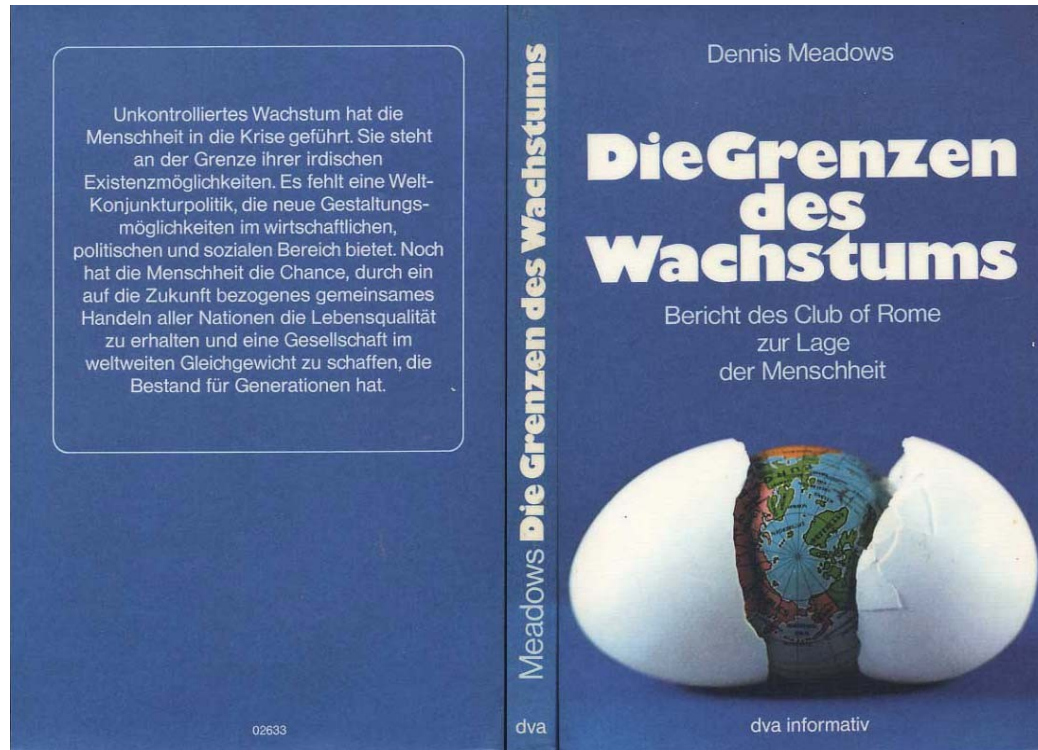
Introduction

The Limits to Growth – World3 Standard Run

Introduction

The Limits to Growth – 1972 / 2004

Introduction

The Limits to Growth – World3 Model

[Click Me](#)

[Click Me](#)

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 – <u>Link</u>

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)

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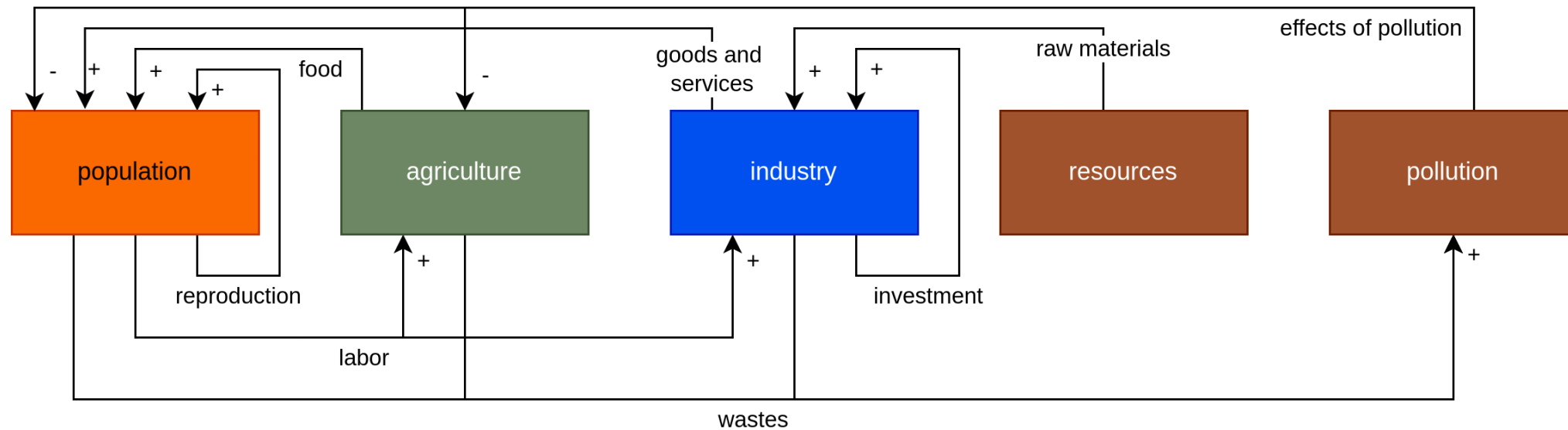
World3

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)
- Laundry list for "Birth rate":
  - Population
  - Standard of living
  - Food Quality
  - Food Quantity
  - Education
  - Contraceptives

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

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
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
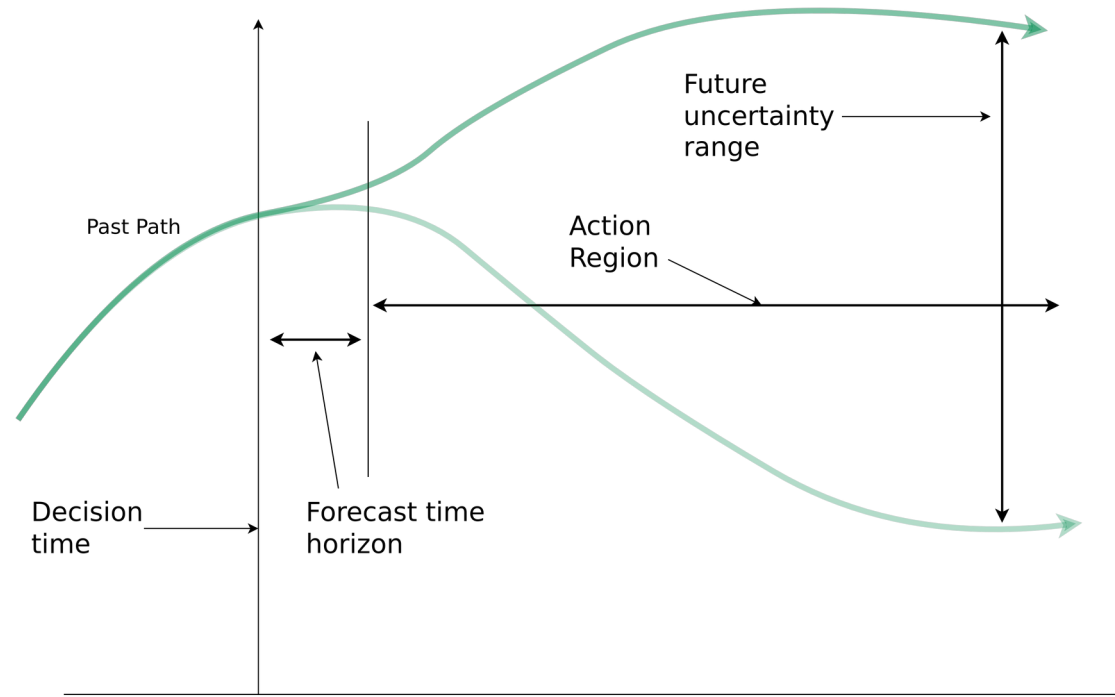
World3
Agriculture

- 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

World3
Simulation Results

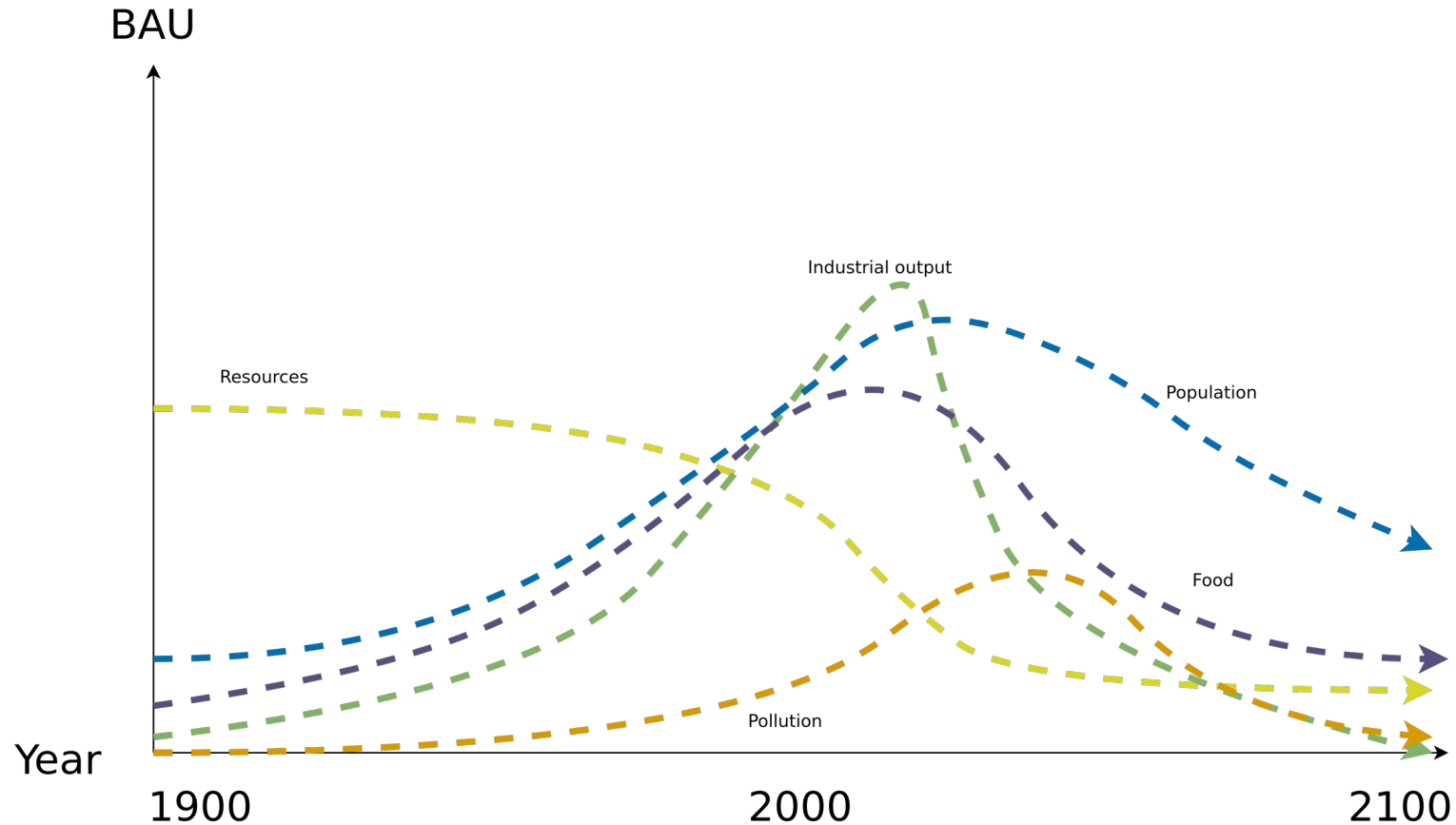- Varies scenarios based on different assumptions
- 4 popular scenarios:

World3
Simulation Results

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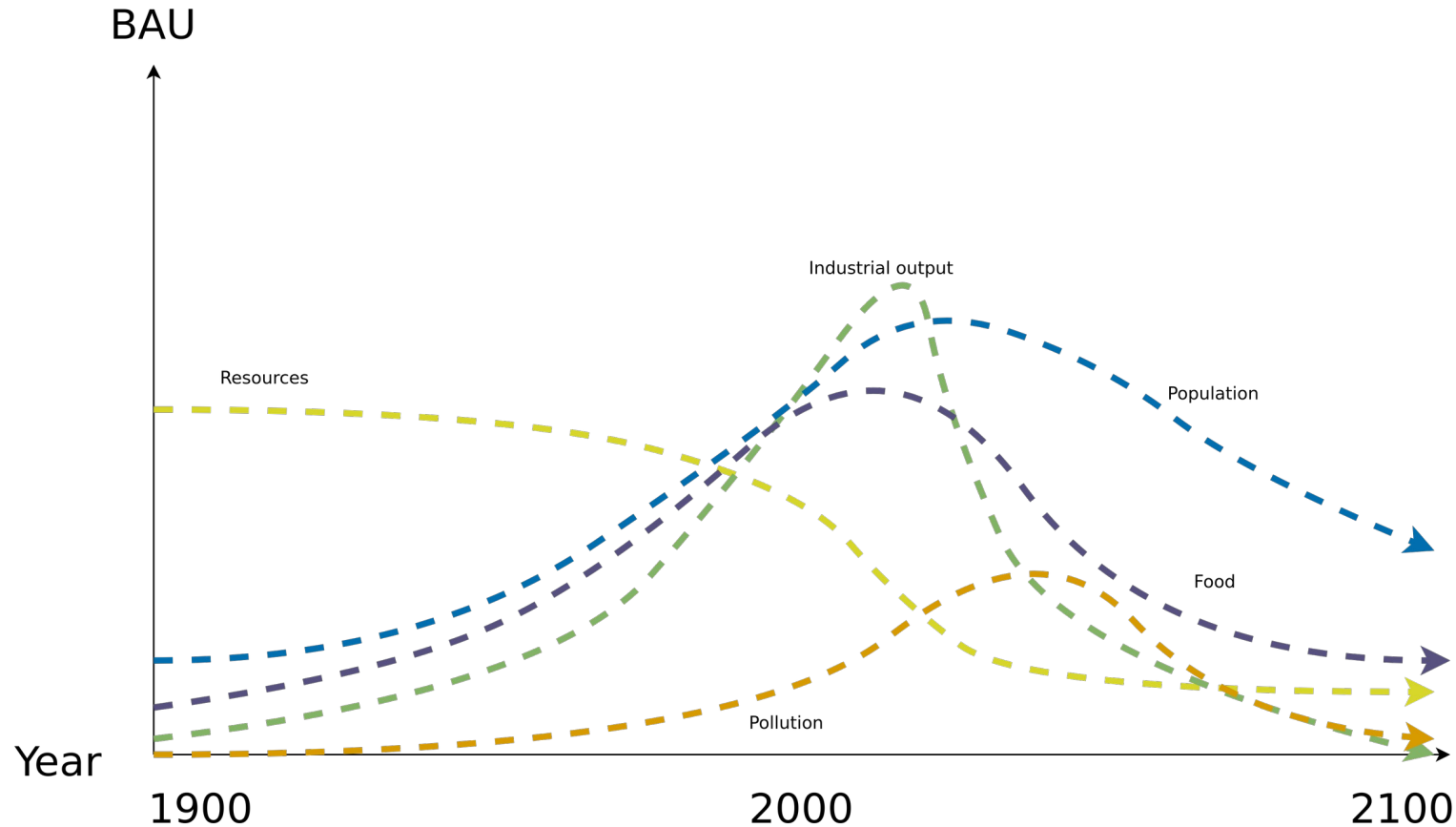- 4 popular scenarios:
  - Business-as-usual (BAU)

World3
Standard Run – Business-as-Usual (BAU)

World3
Standard Run – Business-as-Usual (BAU)

→ Collapse due to natural resource depletion

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

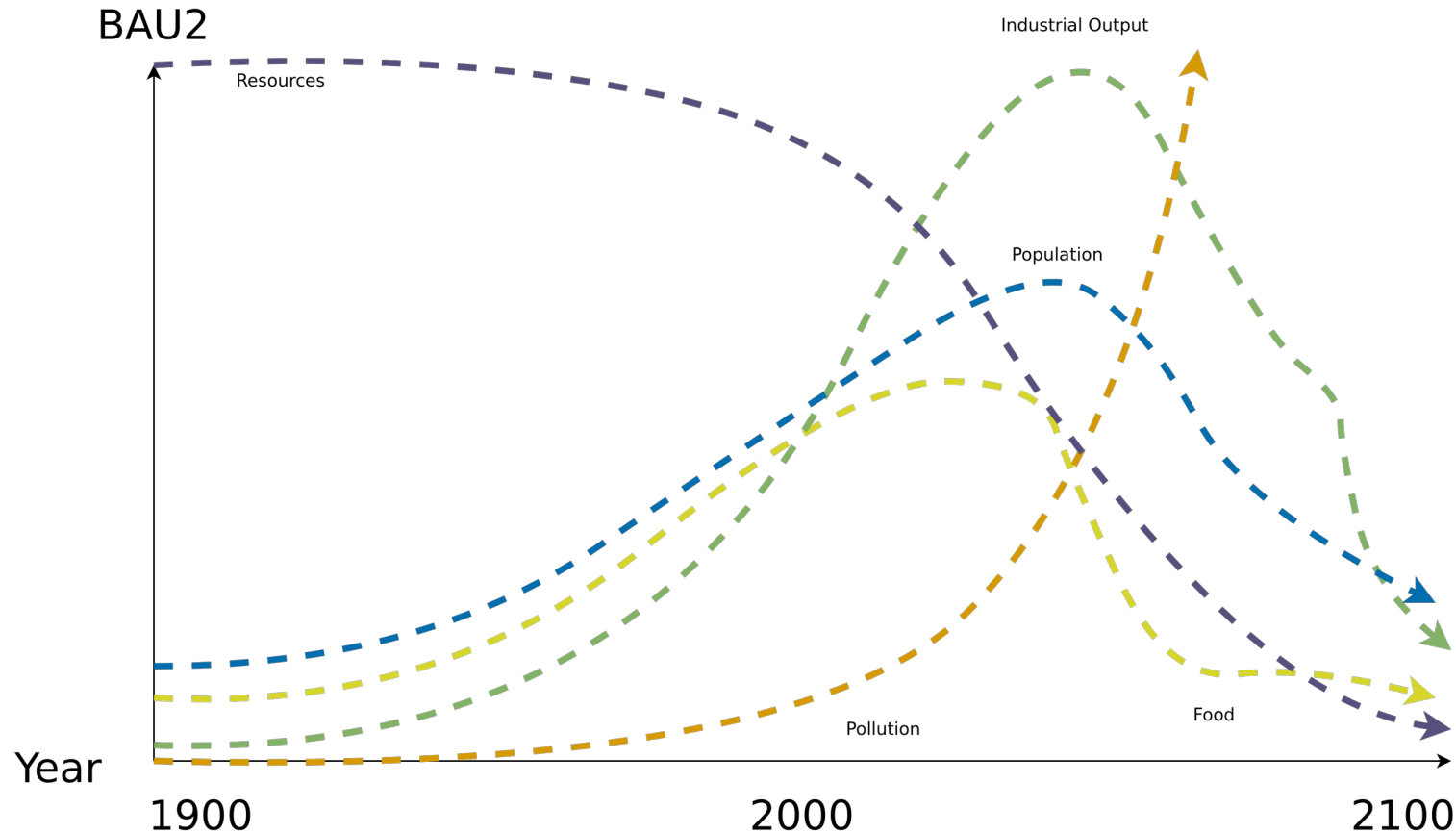The Limits to Growth – TU Clausthal

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World3
Simulation Results

- Varies 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)

→ Collapse due to pollution (climate change equivalent)
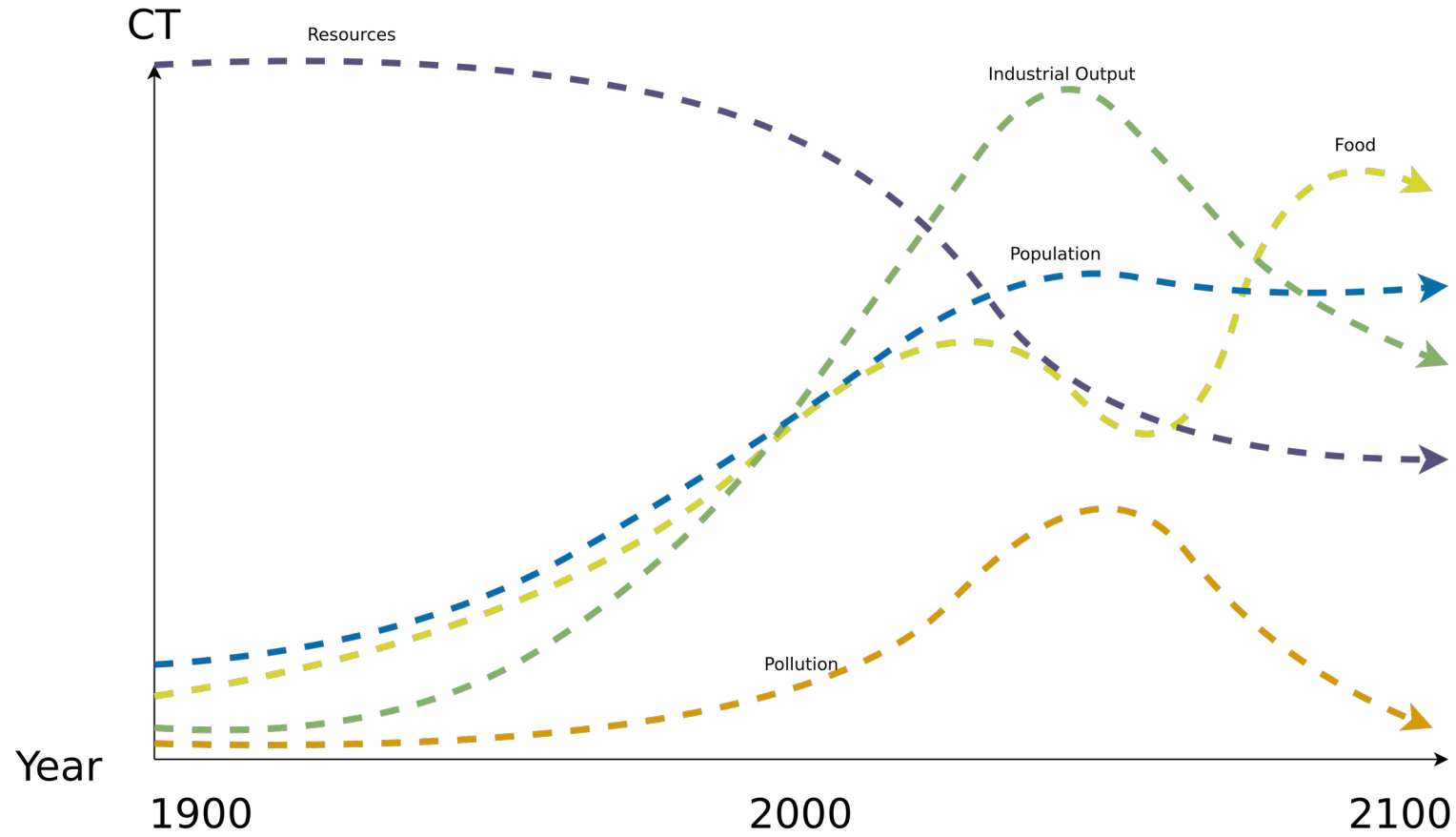
The Limits to Growth – TU Clausthal

World3
Simulation Results

- Varies 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
Standard Run – Comprehensive Technology (CT)

World3
Standard Run – Comprehensive Technology (CT)

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

World3
Simulation Results

- Varies 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
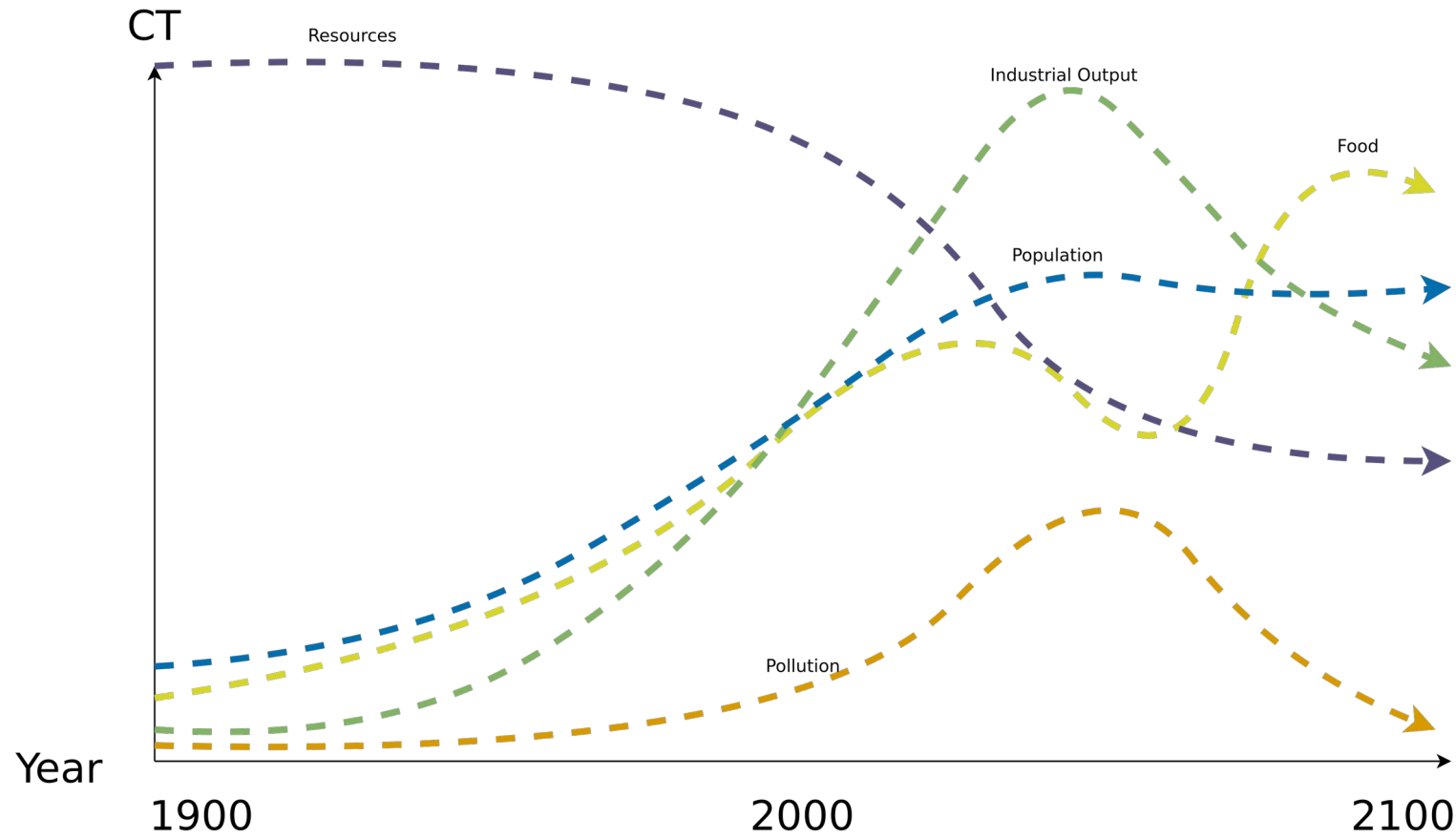 - Stabilized World (SW) → CT + changes in societal values and priorities

World3

Standard Run – Stabilized World (SW)

World3
Standard Run – Stabilized World (SW)

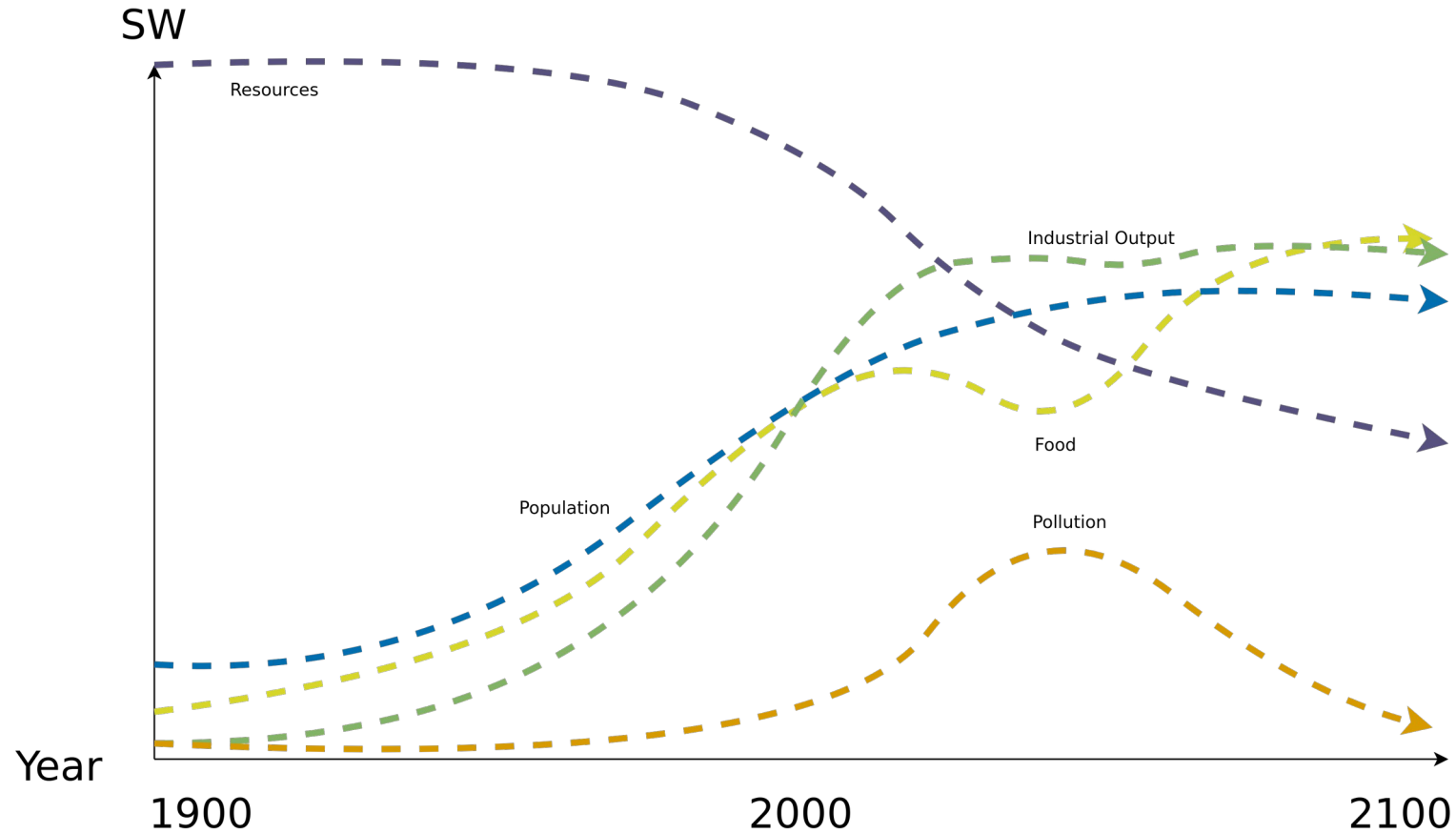→ Population stabilizes in the twenty-first century, as does human welfare on a high level

World3
Simulation Results

- Varies 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**
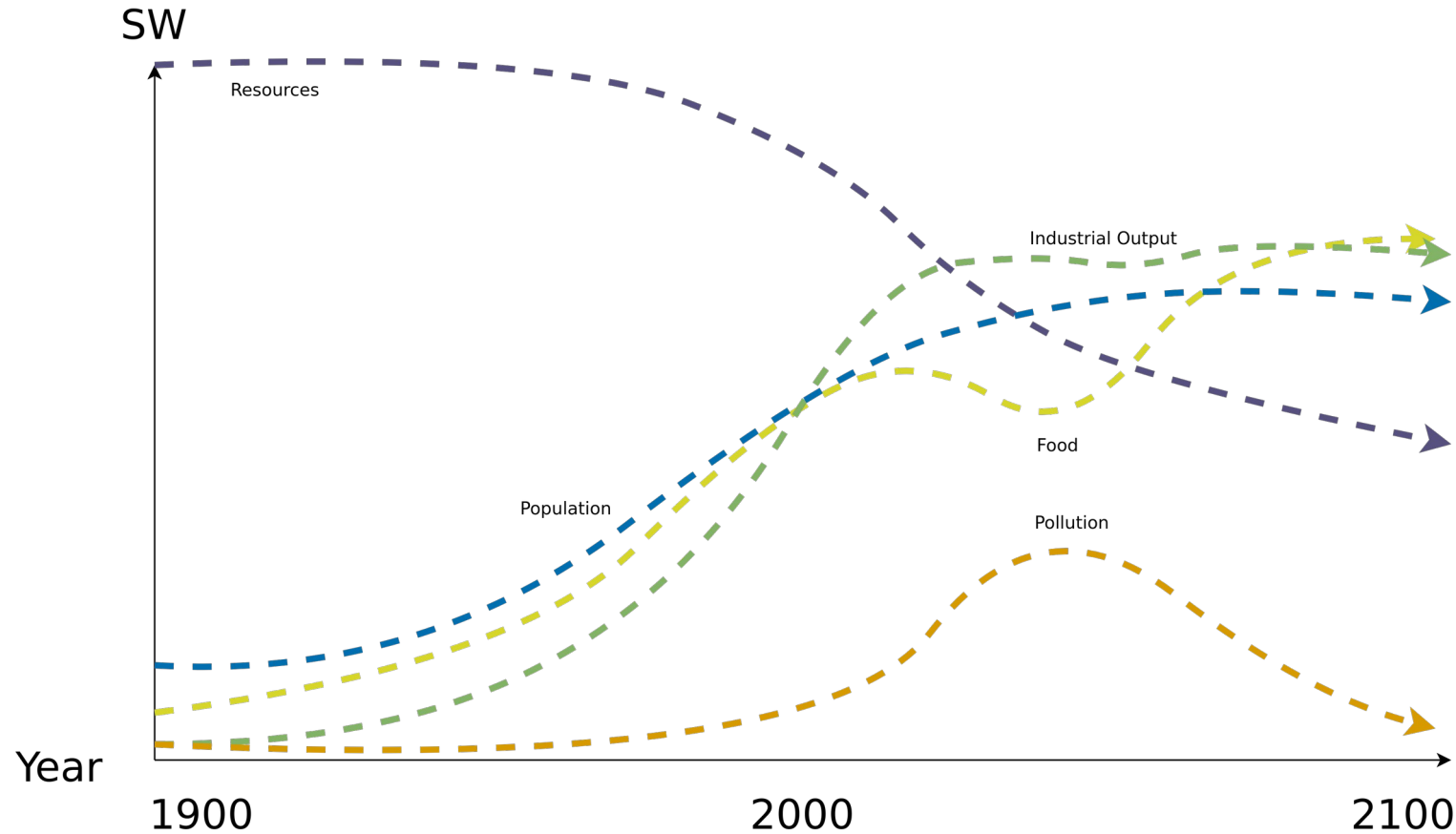
World3

Were are we now?

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

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

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 to complex and oversimplification

CONCLUSION

Conclusion

- 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 E05

Exercise E05

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*.
- Brian Hayes (2012) – Computation and the Human Condition (Harvard SEAS) – [Link](#)

Questions?