Systems Thinking as a core competence for Sustainable Development and Digital Transformation

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Systems Thinking & System Dynamics for Sustainable Development

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Agenda

1. Introduction
2. The concept of Sustainable Development (SusDev)
3. Recap of Systems Thinking and System Dynamics main concepts
4. Systems Thinking, System Dynamics and the SYSTEMA project
5. Simple examples of ST/SD for SusDev
6. Simple examples of ST/SD-based Archetypes for SusDev (quick overview)
7. SD/ST literature for SusDev
8. SusDev and policy analysis (coffee break approx. 11/11:30)
9. SusDev and the UN Agenda 2030
10. SD-based ILEs and SusDev
11. SusDev and the Green Deal
12. Systems Thinking and System Dynamics for SusDev – Discussion
13. Looking ahead: the link between SusDev and Digital Transformation

Before starting…

- We live in a world that is rapidly changing
- A new digital era is beginning and that can be identified by accelerating technological innovations, shifts in the way people live, transact and socialize.
- *Sustainability* is the key to a correct management of the interplays between the various "dimensions" of our society.
- And what about ***sustainable development*** (?)

Defining Sustainable Development (SusDev)

Two questions for discussion in class:

- A) What is sustainable development?
- B) Which sectors/dimensions are involved by such a concept?

- **Tip:** The teacher could organize an online poll or simply start the discussion in class

What is Sustainable Development?

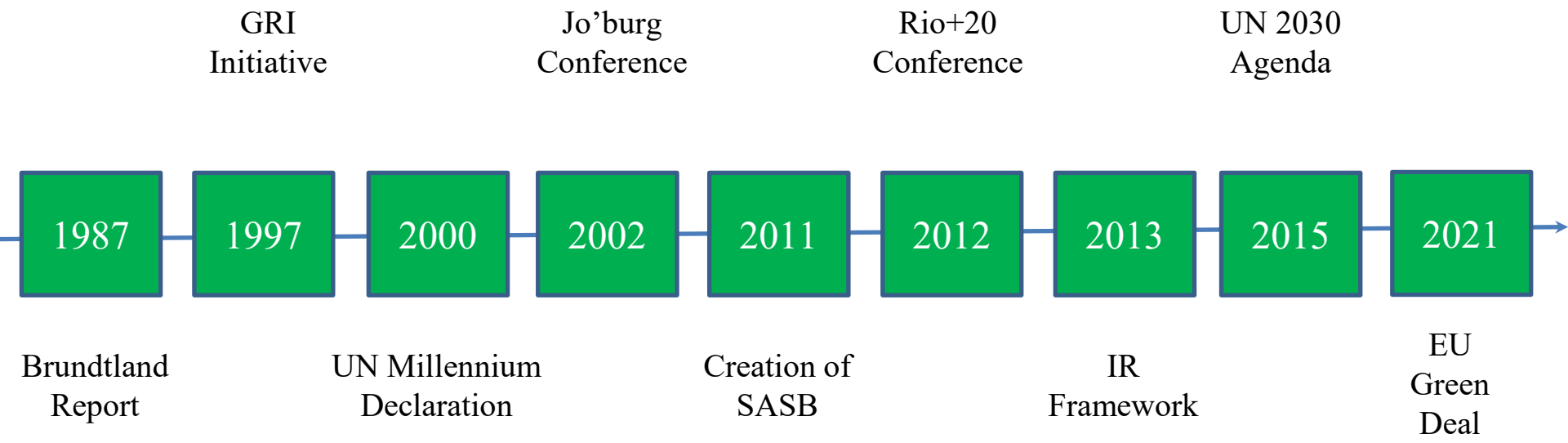
- From IO1: ***Sustainable Development*** could mean different things to different stakeholders, using different temporal and spatial dimensions.
- Sustainable development is a broad term that encompasses many *dimensions* that cannot be easily measured and/or quantified

What is Sustainable Development?

- *Sustainable Development* was defined in the World Commission on Environment and Development's 1987 Brundtland report "Our Common Future" as the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

- 3 main pillars of sustainable development: ***economic growth, environmental protection, and social equality***.
  - Multi-dimensional issue …
  - … characterized by high interconnectedness of factors
  - Subsequently, policies should account for and reflect such complexity and interplays

The road toward the modern concepts of "Sustainable Development"



A path full of treaties, agreements, deals, etc.

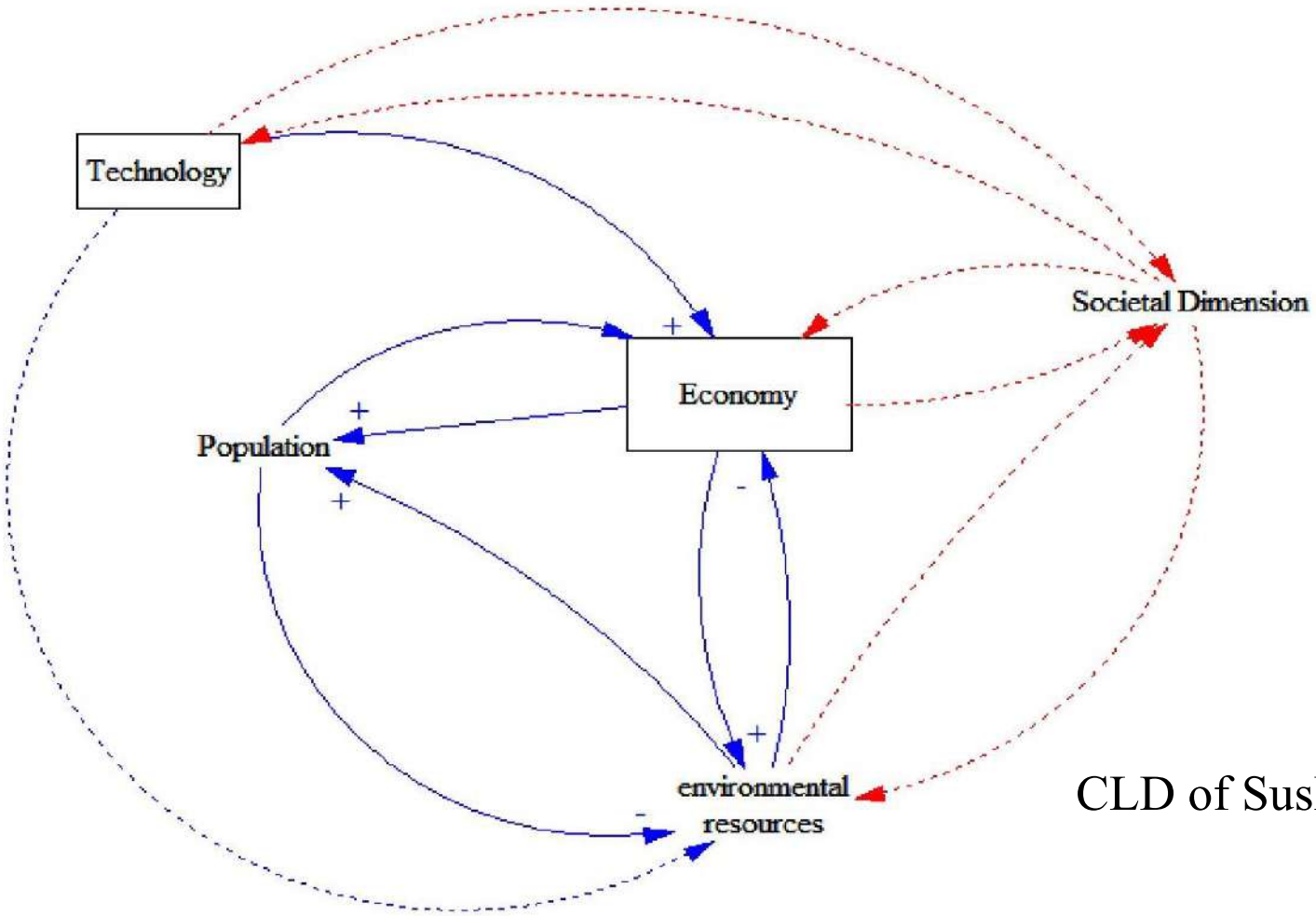
SusDev in the context of the SYSTEMA Project

- *Sustainable Development definitions in the context of the SYSTEMA project*

- Many definitions focus on the interplays among the three dimensions aforementioned – i.e., economic, social, and environmental (e.g., Robinson, 2004)

- Some others emphasize the importance of technological innovation as the path to be travelled (e.g., Drucker, 2014).

SusDev in the context of the SYSTEMA Project



CLD of SusDev dimensions

From IO1 - SYSTEMA

SusDev: problems, opportunities, and challenges

- Tip: Start and facilitate discussion in class here

SusDev: problems, opportunities, and challenges

- Causality and complexity to be represented and simulated
- Non-linearities and delays are relevant for SustDev
- Relevance of both qualitative (problem articulation) and quantitative (behavior of time) modelling and simulation
- Understanding of short- as well as medium- and long-term consequences of decisions and actions
- Role played by people's behavior

- A "role" for *simulation modelling principles and tools* …
- … **Systems Thinking** and **System Dynamics**

Systems Thinking (ST) in brief

- Systems Thinking is "a way of seeing and talking about reality that helps us better understand and work with systems to influence the quality of our lives. (…). It also involves a unique vocabulary for describing systemic behavior, and so can be thought of as a language as well" (Kim, 1999, p. 2).
- Looking at Systems Thinking from various perspectives:
  - it is a holistic approach to analyze how systems work and can be managed;
  - it is also a set of techniques and tools that will support analysts, learners, and decision-makers in facing problem-solving tasks and complex issues.
  - And, it can be also seen as a skill or even a "discipline" in itself (see Peter Senge and his well-known book titled "The Fifth Discipline", 1990).

System Dynamics (SD) in brief

System Dynamics can be considered as …

- "a perspective and a set of conceptual tools that enable us to understand the structure and dynamics of complex systems.
- System Dynamics is also a rigorous modeling method that enables us to build formal computer simulations of complex systems and use them to design more effective policies and organizations. [. . .]
- Together, these tools allow us to create management flight simulators – microworlds where space and time can be compressed and slowed so we can experience the long-term side effects of decisions, speed learning, develop our understanding of complex systems, and design structures and strategies for greater success"

(Sterman, 2000, p. vii).

System Dynamics (SD) in brief

- A computer-assisted methodology (Forrester 1961 and 1968; Richardson and Pugh 1981; Sterman 2000)
- Based on information-feedback control theory
- Qualitative modelling and quantitative simulation tools
- The mathematical model reproduces the *behaviour* of the system under investigation in light of specific policies being implemented.
  - So, key is the relationship between ***structure*** and ***behavior***
  - Compared to Systems Thinking, SD adopts a more ***quantitative approach*** to modelling

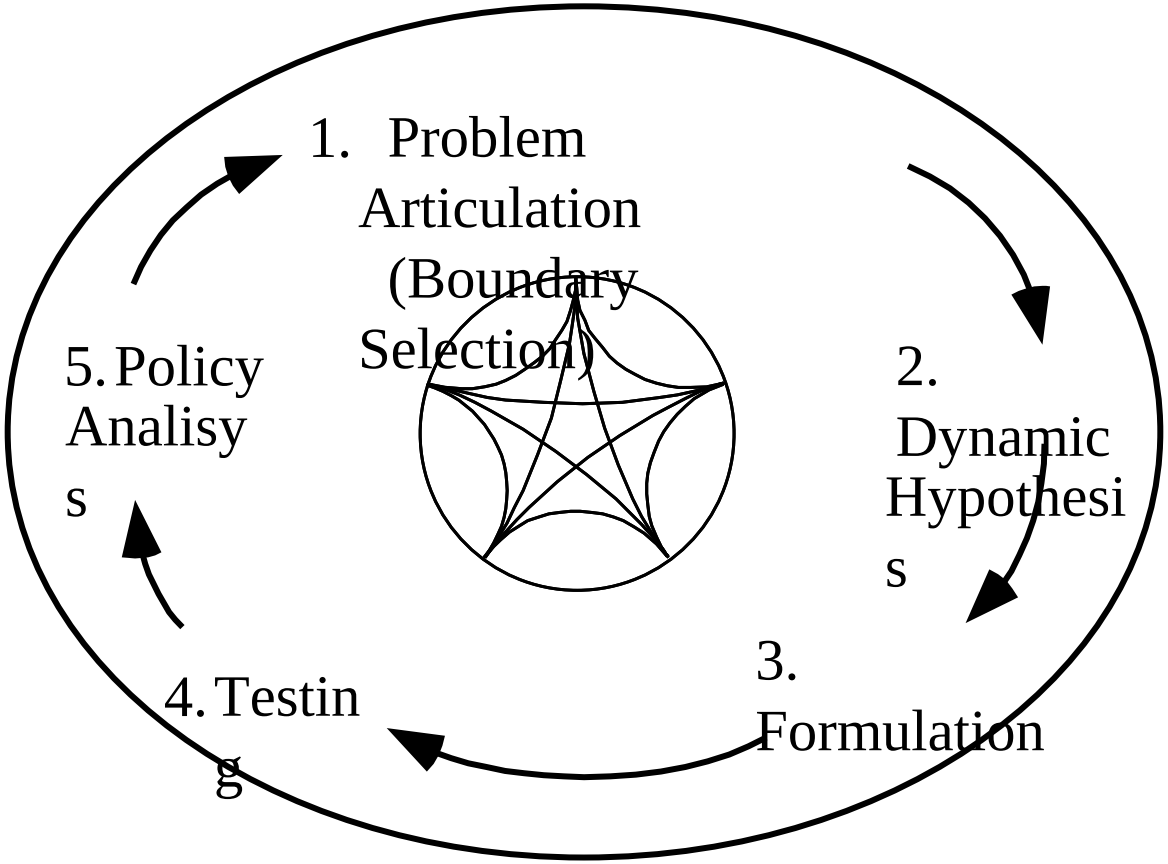
System Dynamics (SD) in brief

- *System Dynamics key concepts:*
- 1. Any systemic structure can be represented in terms of the resources (stocks) within that specific system, their rates and the causal linkages (with polarities) connecting such variables.
- 2. Structure produces behavior.
  - Role of simulation: *understanding system behavior*
- 3. Feedback loops, non-linearity and delays are building blocks for generating and understanding dynamic behaviour.
- 4. Closed boundary and endogenous explanation of behavior.

Systems Thinking & System Dynamics: tools

- Three main typologies of tools:
  - Causal maps (Causal loop diagrams, Stock and Flow Diagrams, and System Archetypes);
  - Simulation models;
  - Interactive Learning Environments (ILEs, also known as Management Flight Simulators).

System Dynamics: *The modelling process*



Systems Thinking & System Dynamics: options

- Research method issues/options:
  - Qualitative modelling (problem articulation)
  - Quantitative modelling (simulation)
  - Group Model Building (participatory modelling)
  - Interactive Learning Environments (Management Flight Simulators)
  - Experimental design
  - Policy analysis and decision-making
  - Learning
  - Education and training
  - Research validation
  - …

Systems Thinking, System Dynamics and the SYSTEMA project

- From **IO1:** A search was performed on the scientific databases of Scopus and Google Scholar with the keywords “Sustainable Development”, “System Dynamics” and “Systems Thinking”. The number of returns was extremely high (over 10,000 returns)
- For that reason it was decided that focus would be on applications of SD in sustainable development in regions (countries, cities etc.) or general models that are used for exploration and/or teaching purposes (e.g., environmental and population related examples).
- Additionally, the application of SD in SusDev in individual sectors of the economy or industries merits an investigation of their own
- SusDev as a dynamic, unfolding and never ending process of evolution and change, that requires:
  - behavioral change, leadership innovation, paradigm shifts and sustainability education;
  - policy modelling and learning.

Fundamental structures and modes of behavior

- Structures and modes of behavior:
  - Positive (Reinforcing) feedback loop: Exponential growth (or Decay)
  - Negative (Balancing) feedback loop: Goal-seeking
  - S-Shaped growth
  - Oscillations
  - S-Shaped growth with small overshoot
  - S-Shaped growth with overshoot and collapse
  - Other modes (?) (e.g., chaos)

  - Additionally … System Archetypes … more peculiar patterns of behavior

Before starting… always remember that …

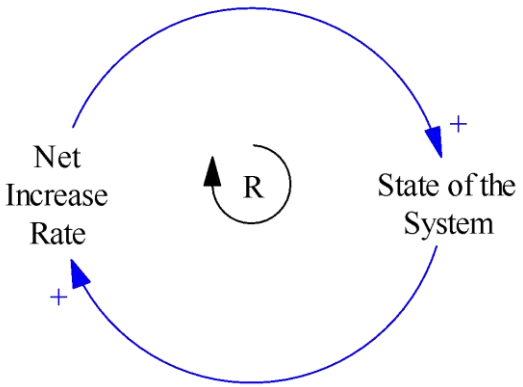
- Computer simulation use "models"… But … what is a "model"?

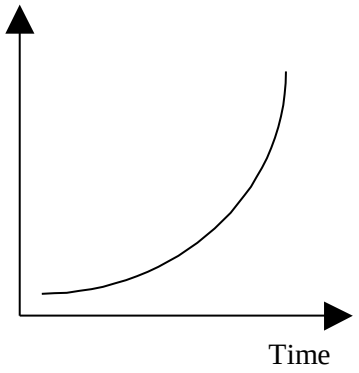
A simplified representation of reality!

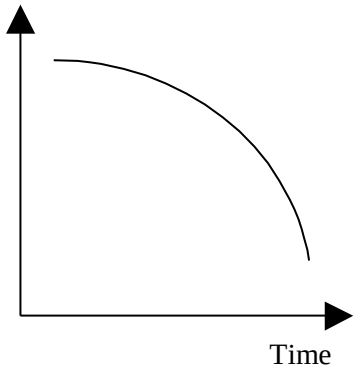
Simple examples of ST/SD for SusDev

Positive Feedback

- Exponential growth arises from a first-order positive (self-reinforcing) feedback.
- The larger the quantity the larger the net increase further augmenting the quantity and leading to even-faster growth.







Examples: growth in a population; a bank account; paper folding

Simple examples of ST/SD for SusDev

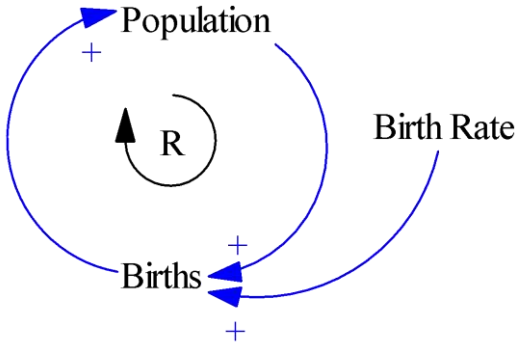
- Experiencing with exponential growth
- A “simple” calculation …
  - Consider to have an A4 paper sheet in front of you (0,0001 mt.)
  - Fold it one time
  - Fold it again
  - Fold it again
  - Fold it again
  - Fold it again
  - …
  - Fold it 100 times
  - …
  - How thick is the folder in front of you?

- Tip: Model this system in class

Simple examples of ST/SD for SusDev

Positive Feedback: examples

CLD



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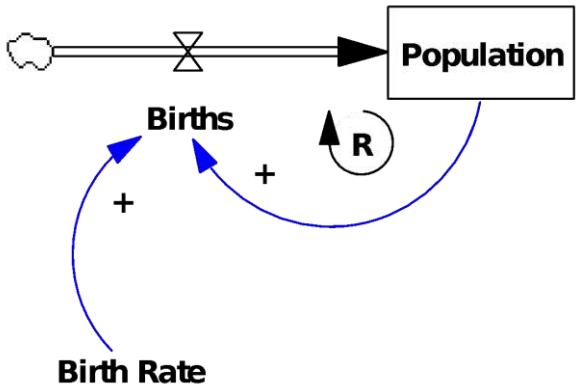
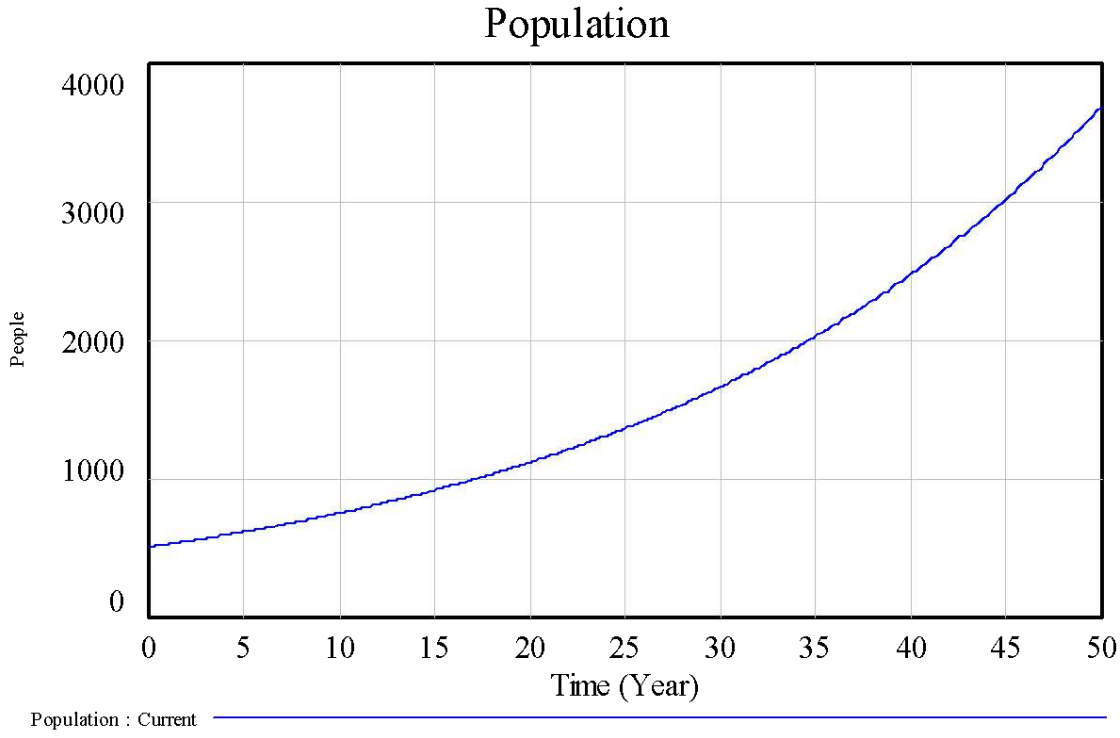
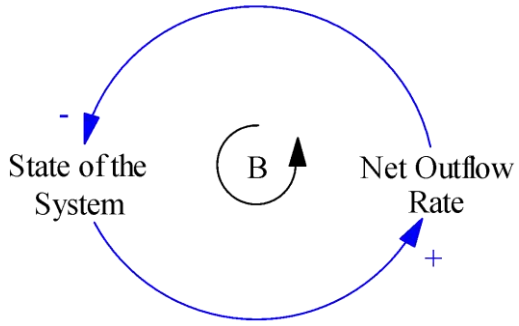


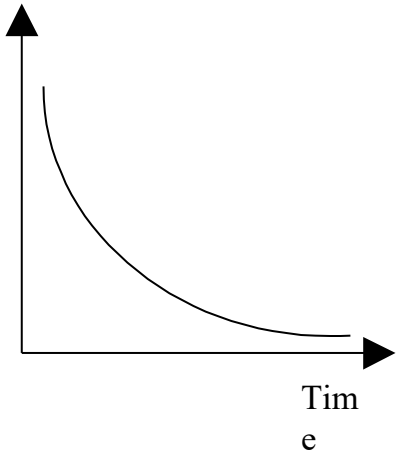


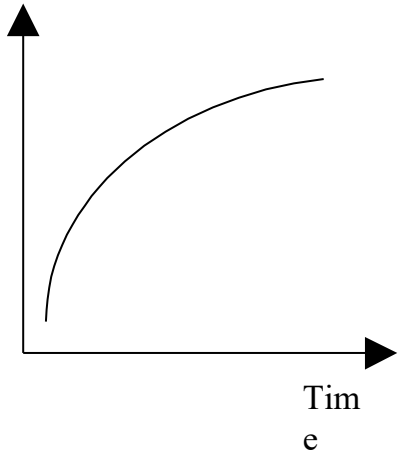
Simple examples of ST/SD for SusDev

Negative Feedback

- First order negative feedback loops generate goal-seeking behavior.
- All negative feedback loops have goals (either explicit or implicit)



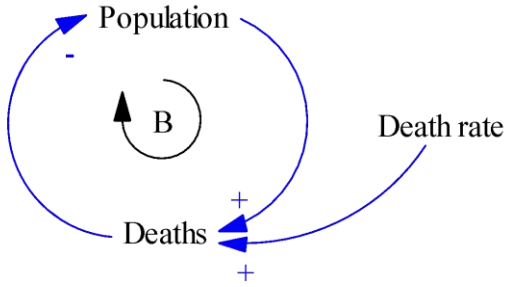




Simple examples of ST/SD for SusDev

Negative Feedback: examples

CLD



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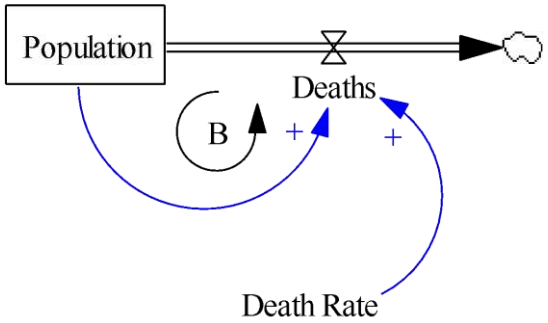
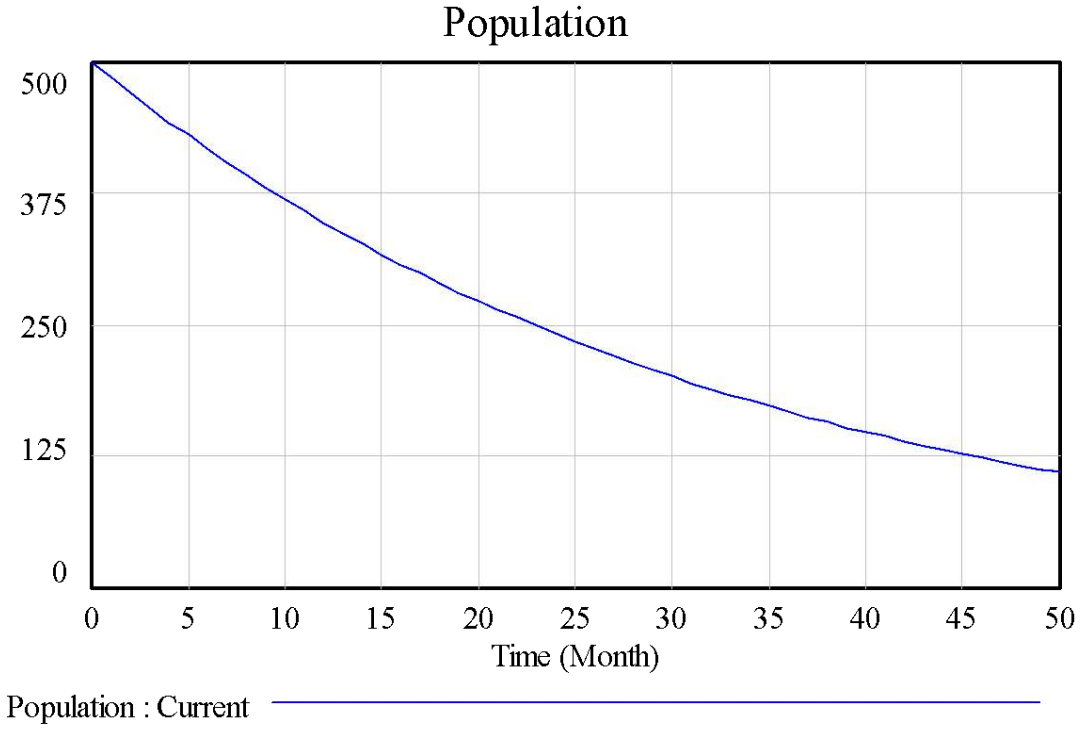


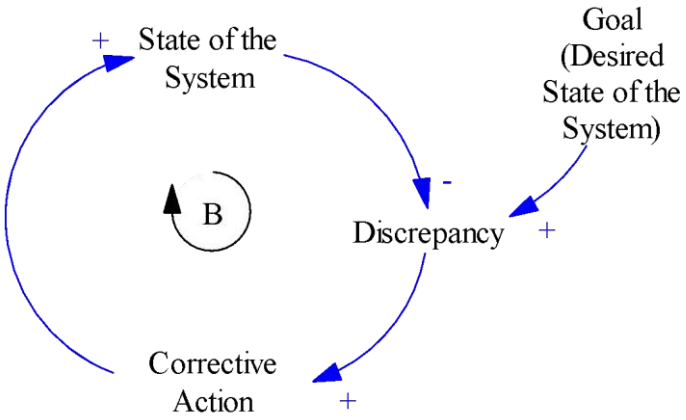


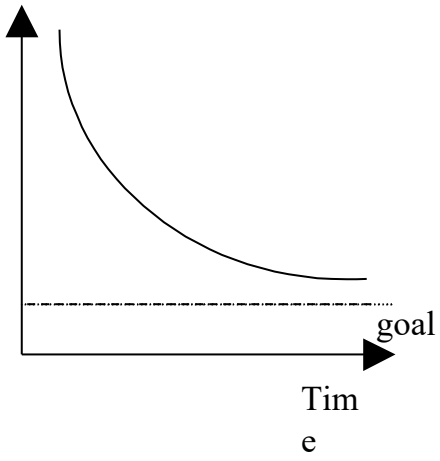
Goal: implicit and equal to zero

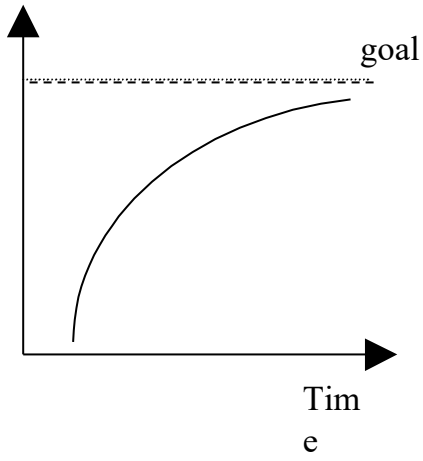
Simple examples of ST/SD for SusDev

Negative Feedback (with explicit goals)

- All negative feedback loops have **goals** (to be made explicit) and they generate goal-seeking behavior.







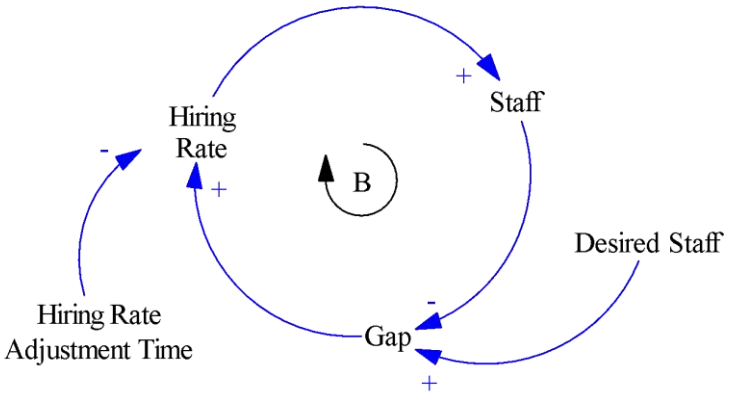
Simple examples of ST/SD for SusDev

- Experiencing with Goal-Seeking
- Describe the actions needed to park your car
- Alternative: describe the actions needed to fill a glass of water to the top of it

Simple examples of ST/SD for SusDev

Negative Feedback (with explicit goals)

CLD



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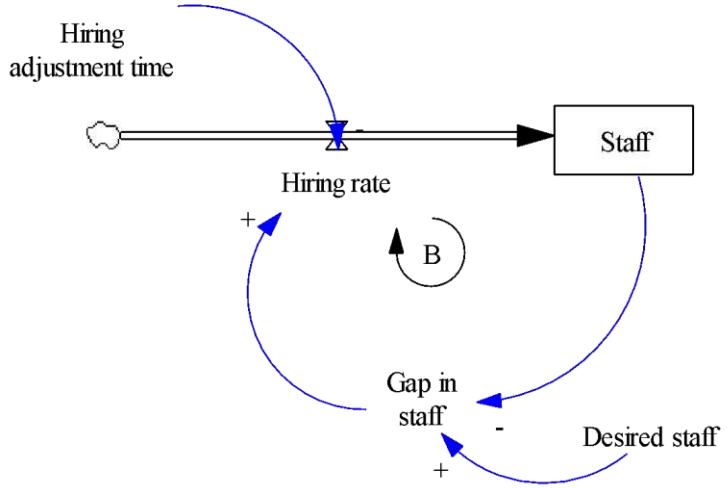
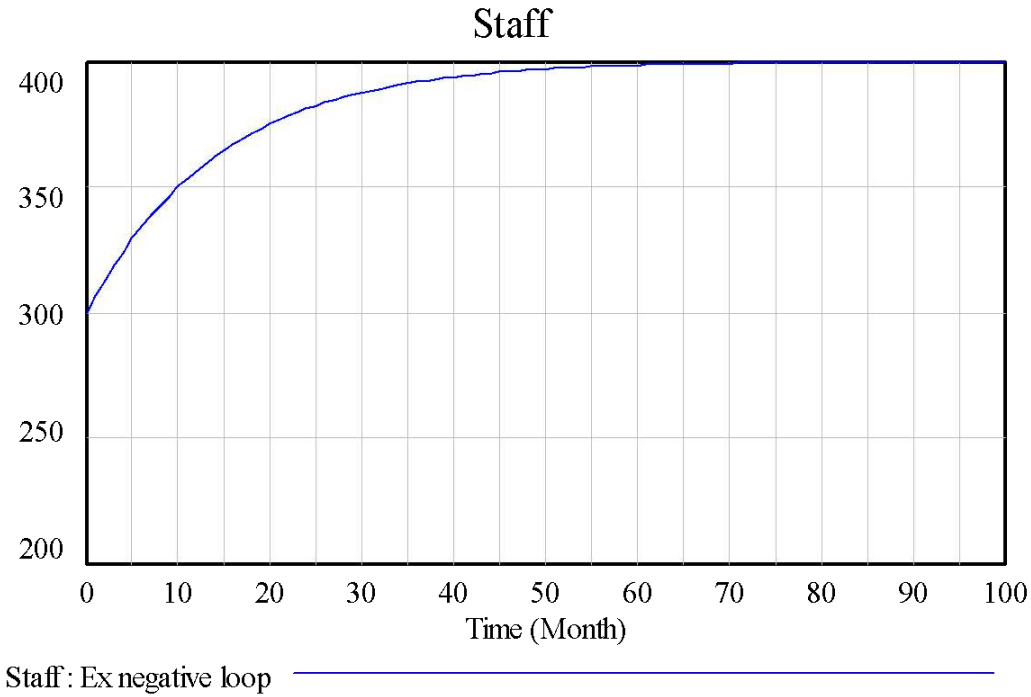
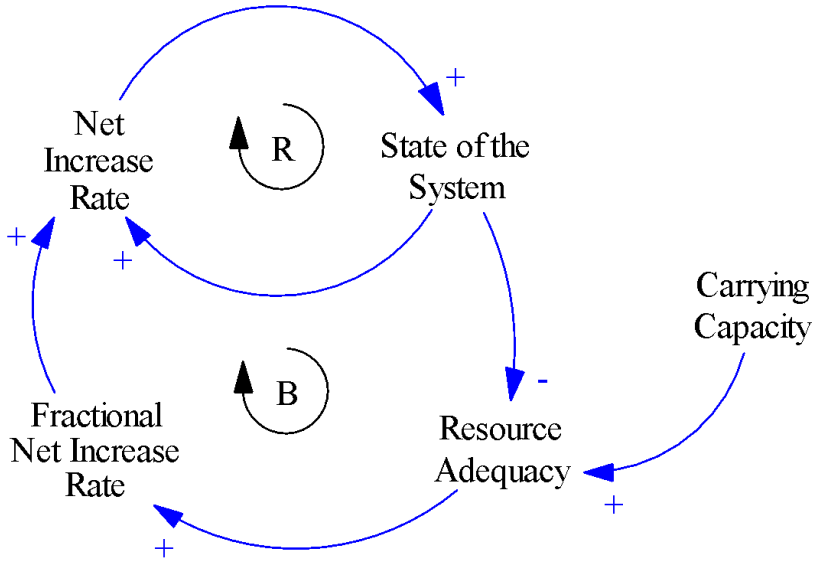


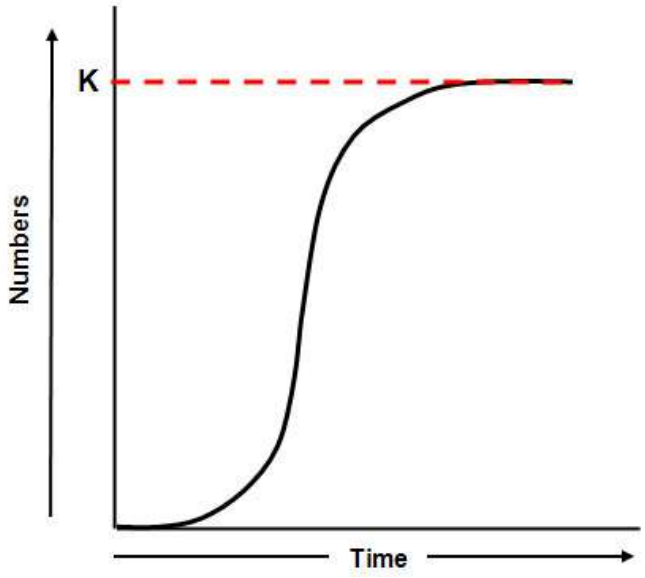


Simple examples of ST/SD for SusDev

Multiple loops - S-shaped growth

- No real quantity can grow forever …
- Multiple-loop systems
- S-shaped growth: two feedbacks combined *and* nonlinearities





- Tip: Introduce the concept of «loop dominance»

Multiple loops - S-shaped growth

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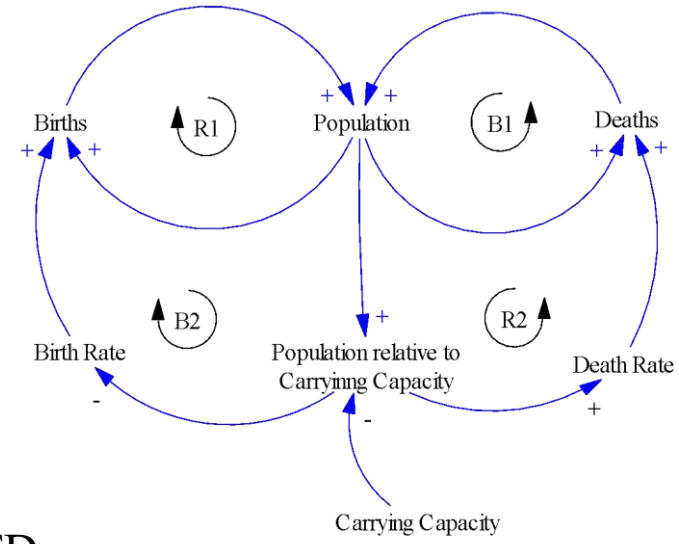

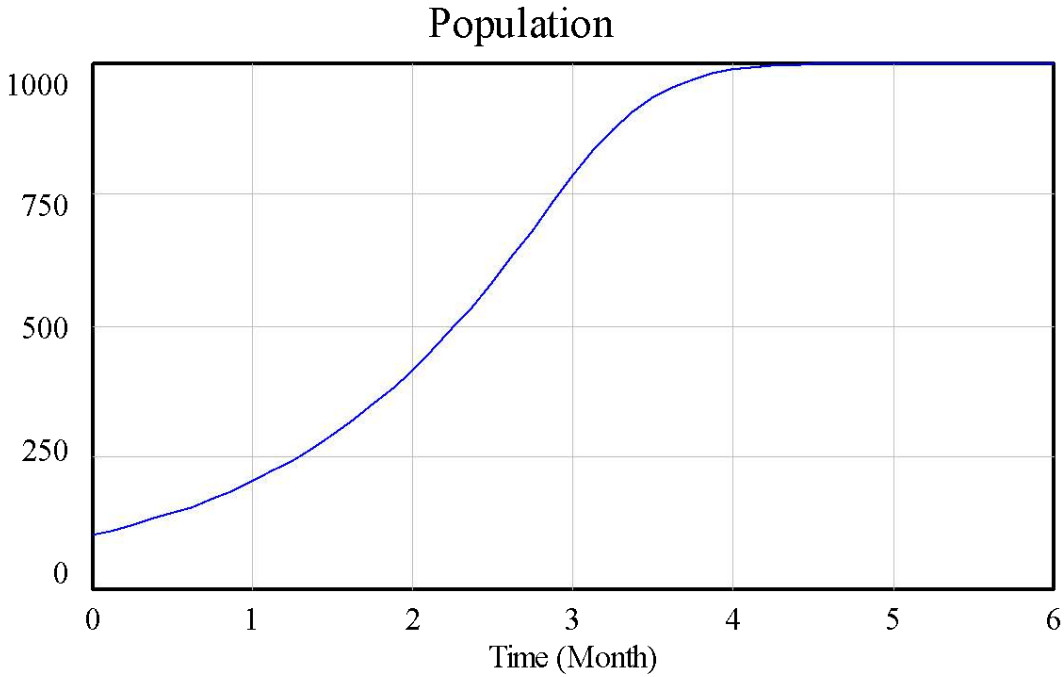

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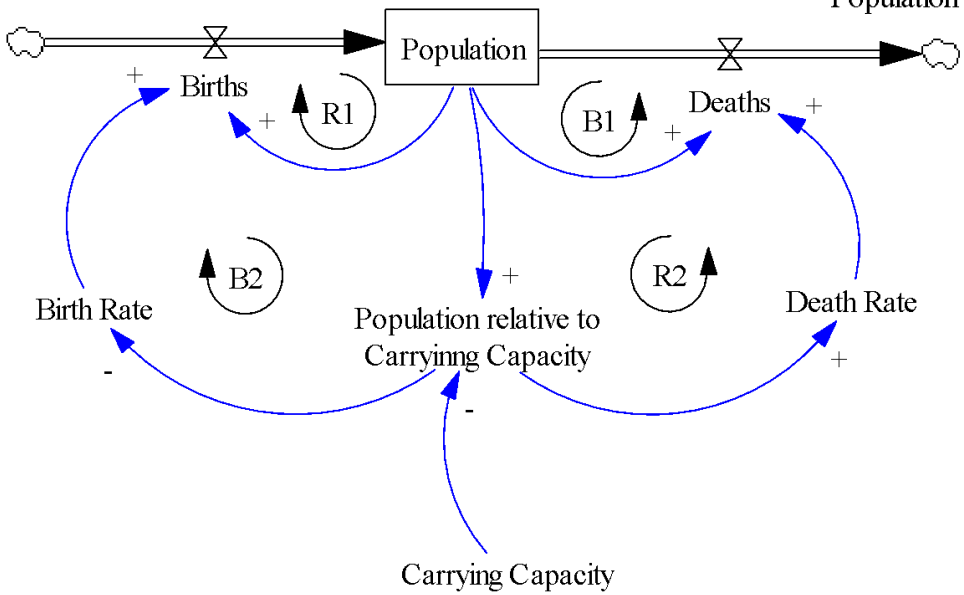


Simple examples of ST/SD for SusDev

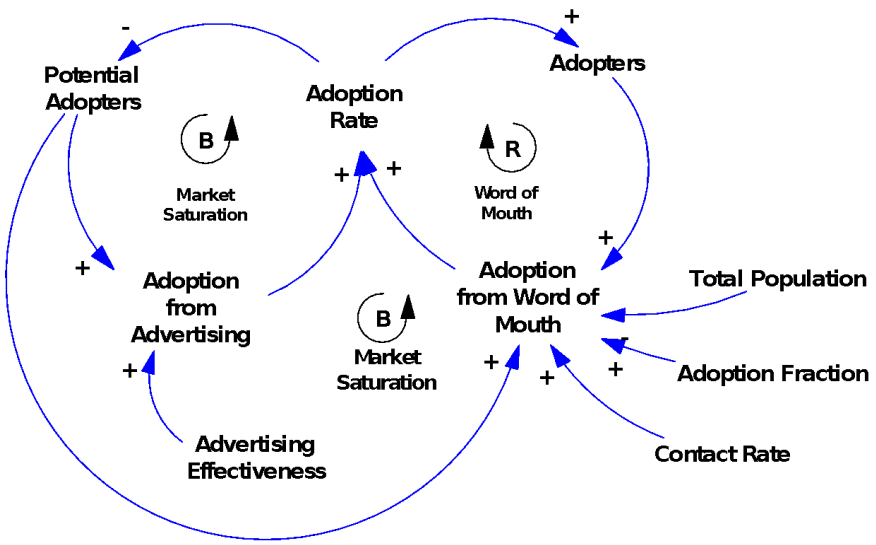
- Experiencing with Limits to growth

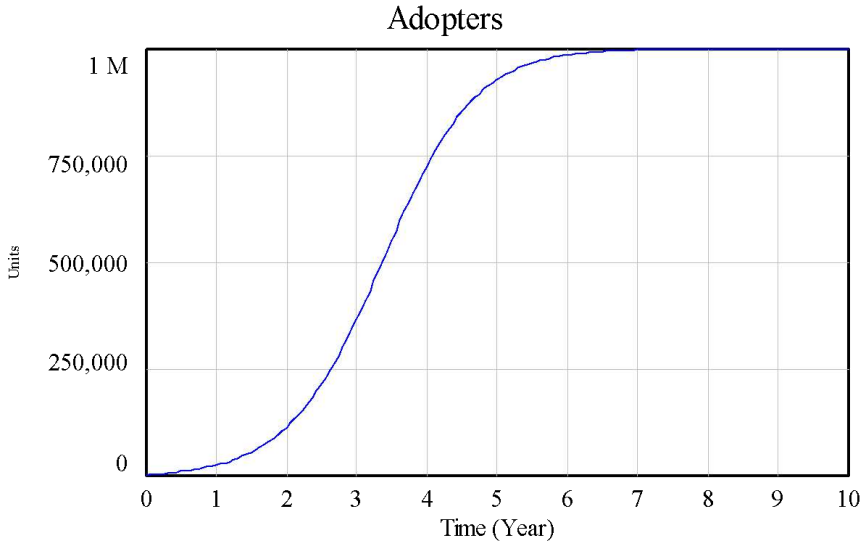
- Consider launching a new product on the market
- You will need to gain new customers through advertising
- And you will exploit the power of word of mouth

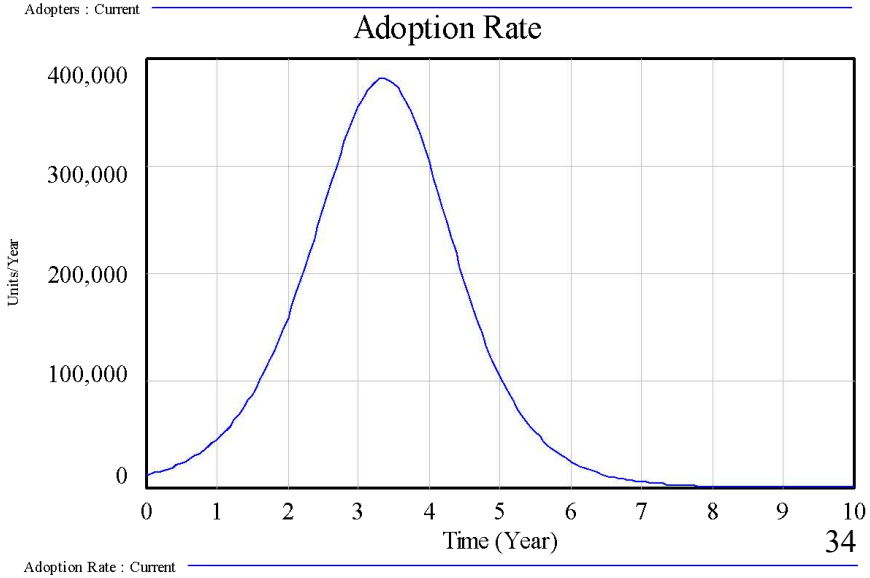
- Which is the dynamic behavior of this system?
  - Sketch a diagram for the variable “Adopters”

Simple examples of ST/SD for SusDev

- Experiencing with Limits to growth

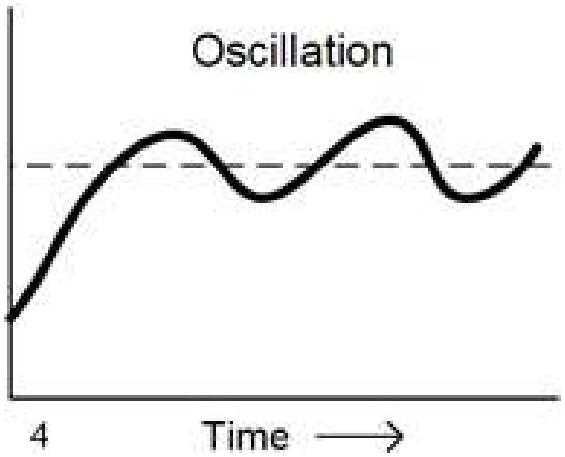


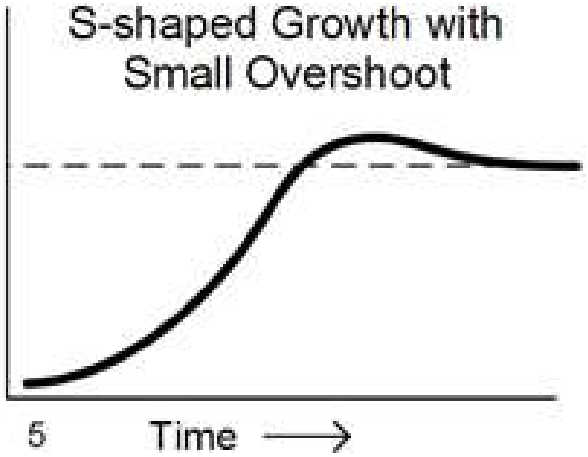


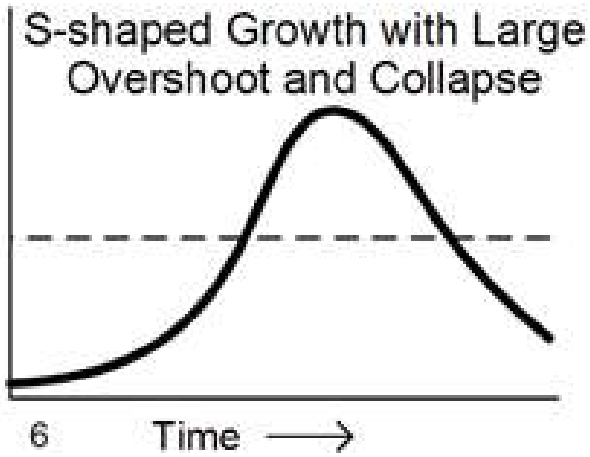


Simple examples of ST/SD for SusDev

Other modes of behavior



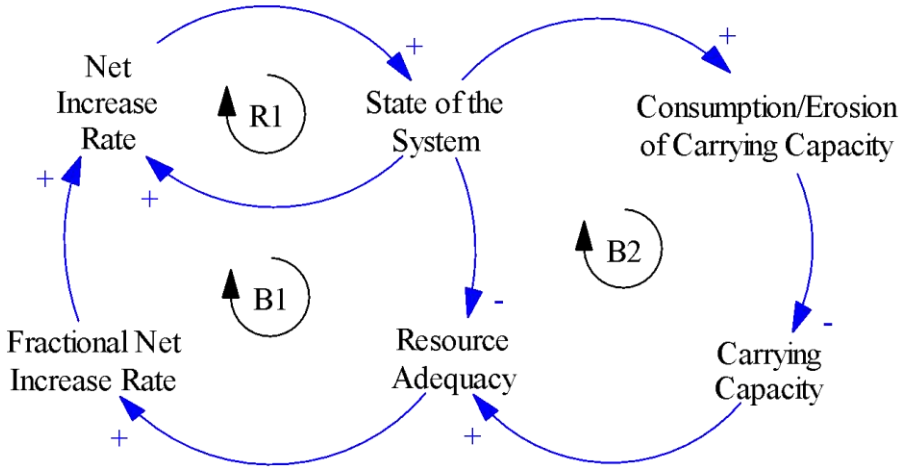


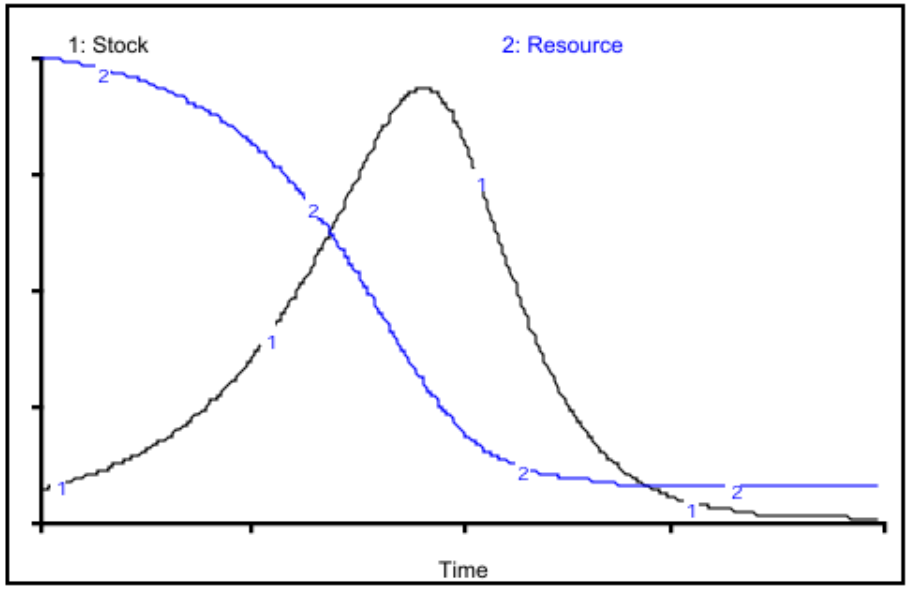


- Tip: Think about examples within the broad field of SusDev and discuss the examples with the class

Simple examples of ST/SD for SusDev

- S-Shaped Growth with small overshoot and collapse

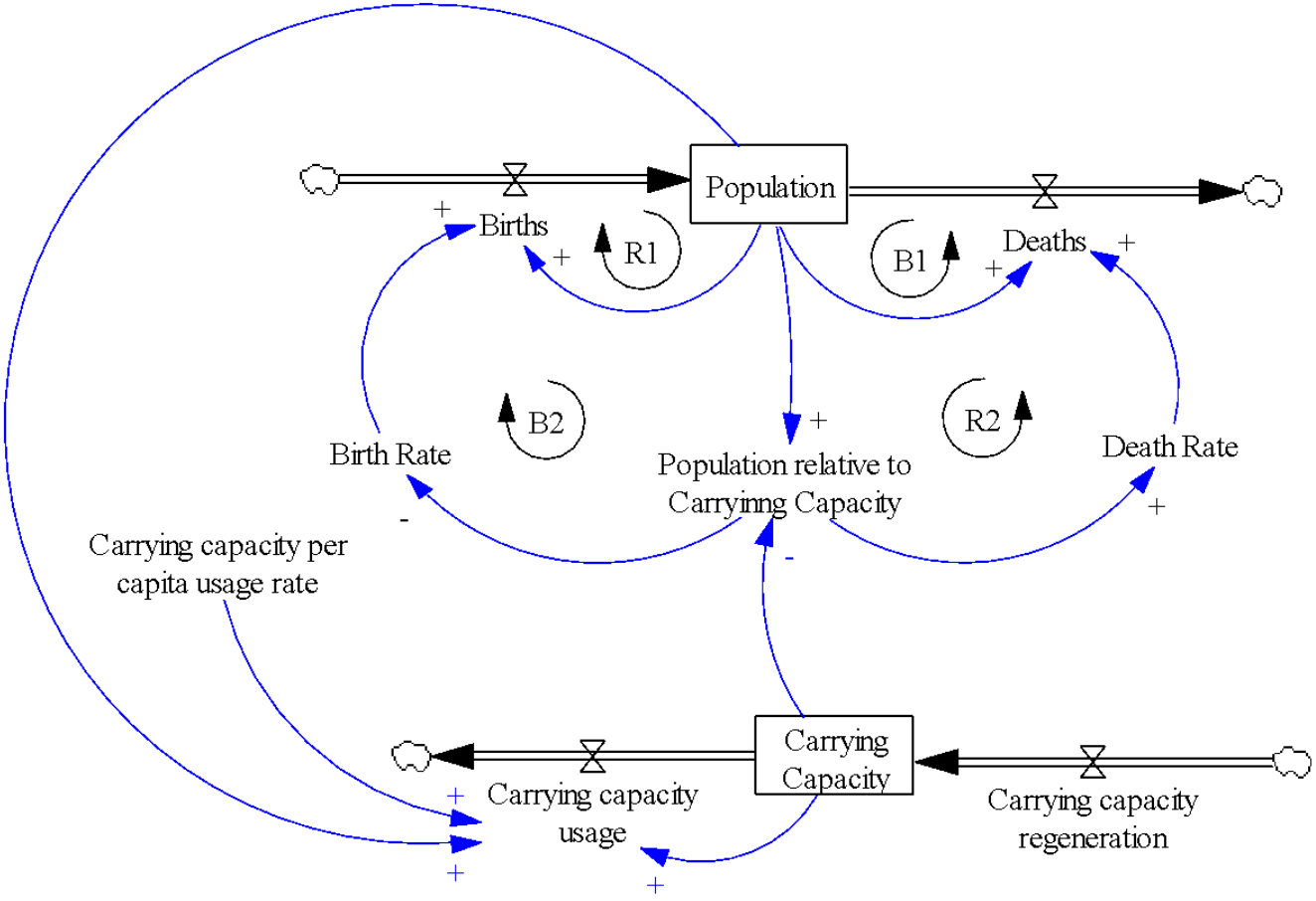




Examples: Petroleum extraction; Deer population

Simple examples of ST/SD for SusDev

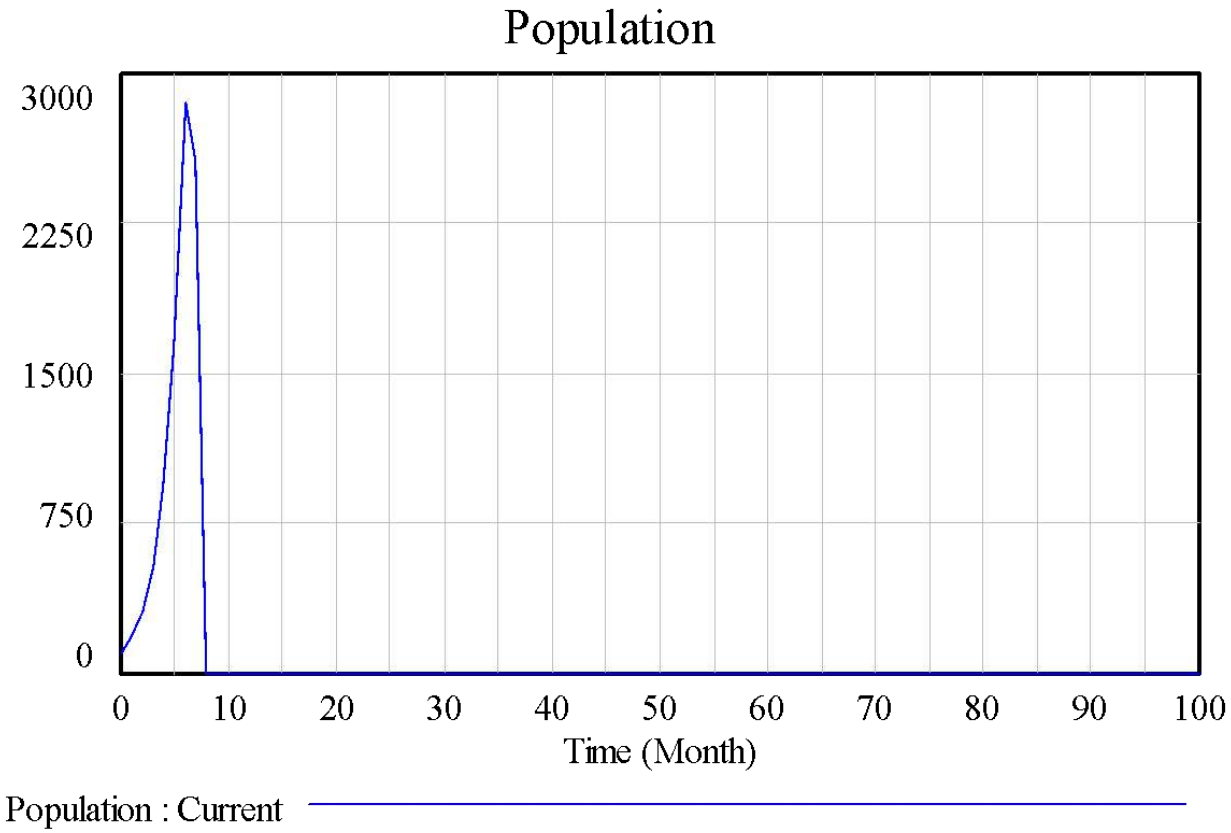
- S-Shaped Growth with overshoot and collapse



- Challenge: which loops were added in this structures?

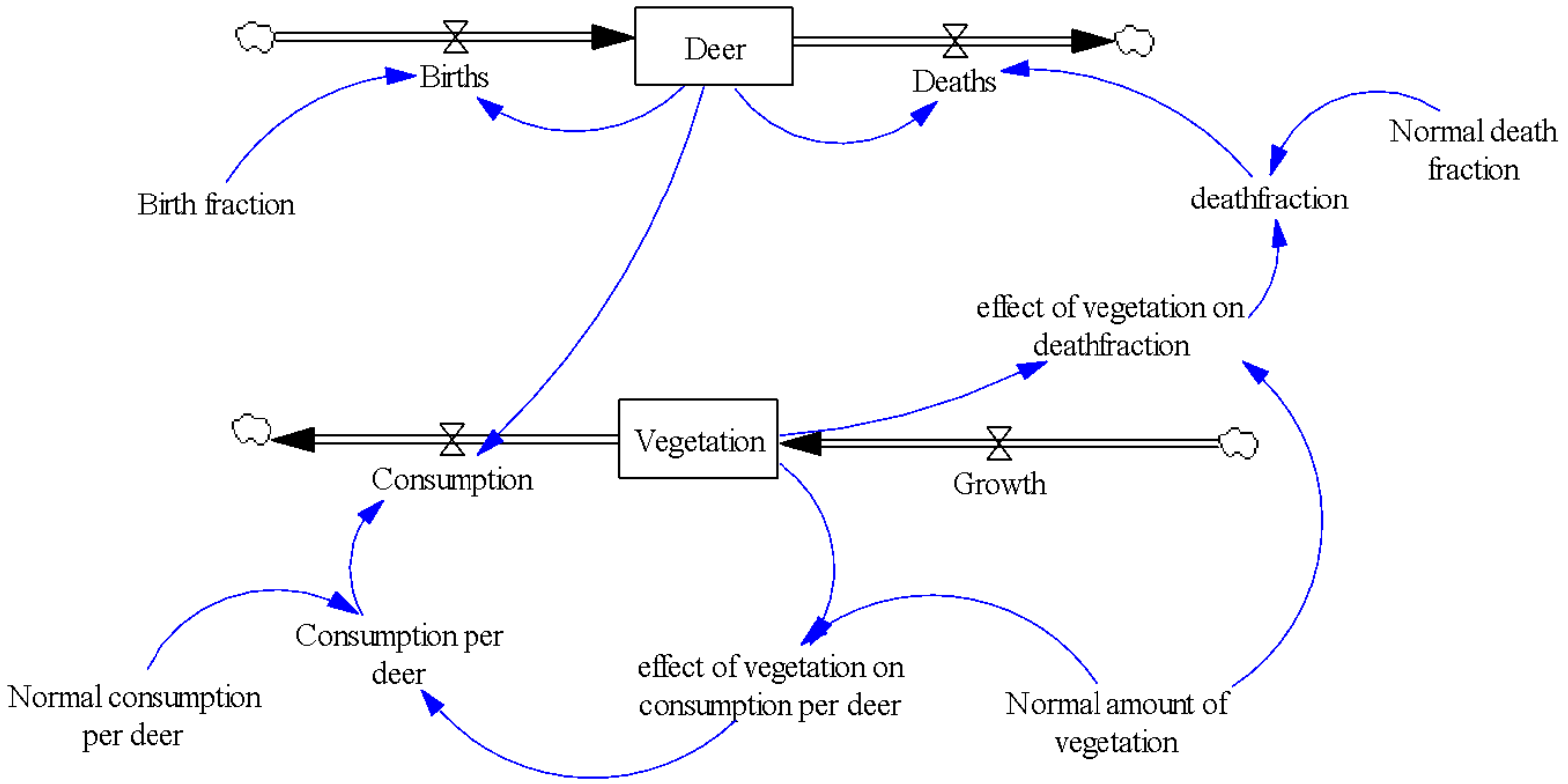
Simple examples of ST/SD for SusDev

- S-Shaped Growth with overshoot and collapse



Simple examples of ST/SD for SusDev

- Reflecting on S-Shaped growth with overshoot and collapse



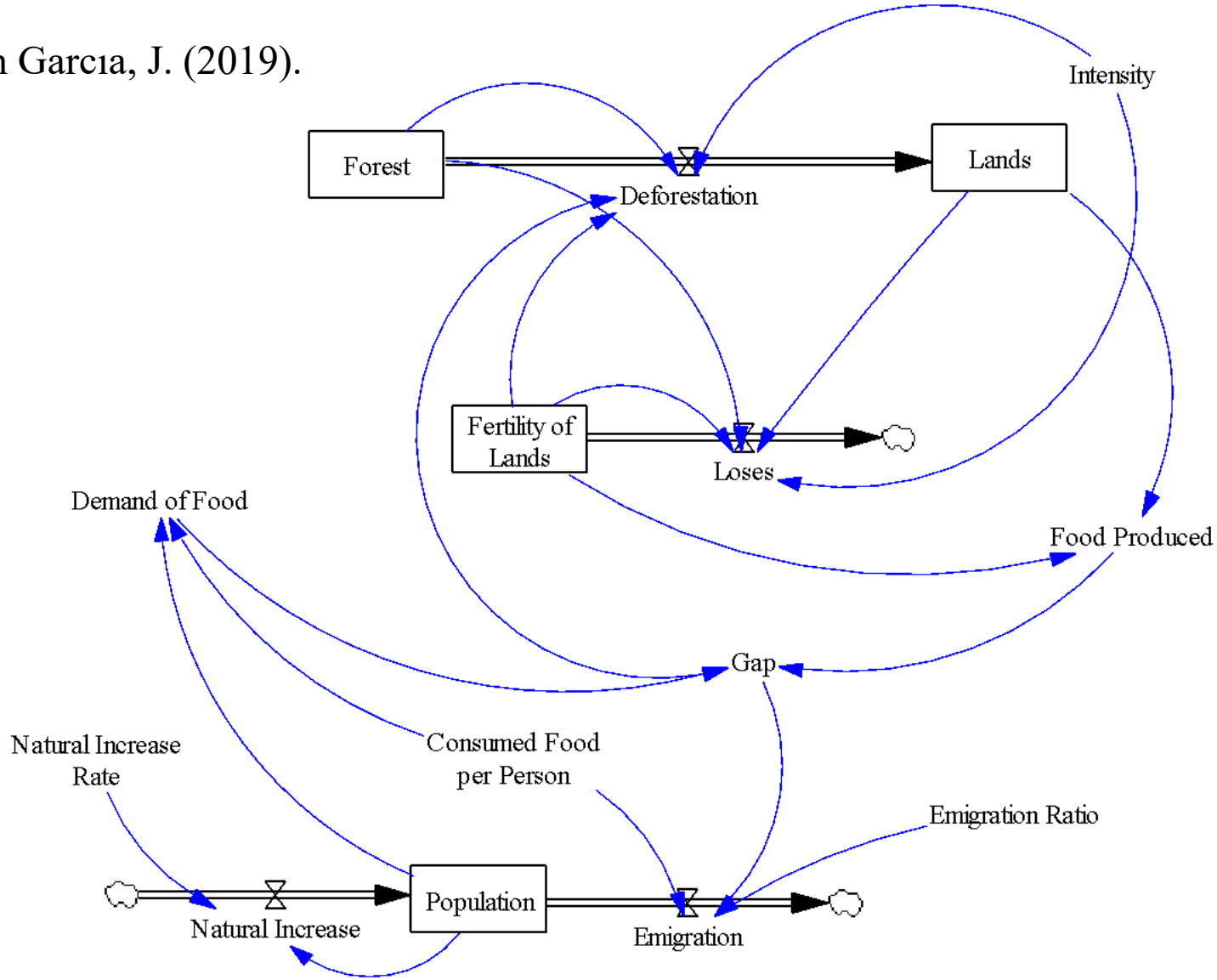
- Tip: Use the «loops» button function provided in Vensim

Source: MIT (1997), Generic Structures: Overshoot and Collapse, Document D4480.

Simple examples of ST/SD for SusDev

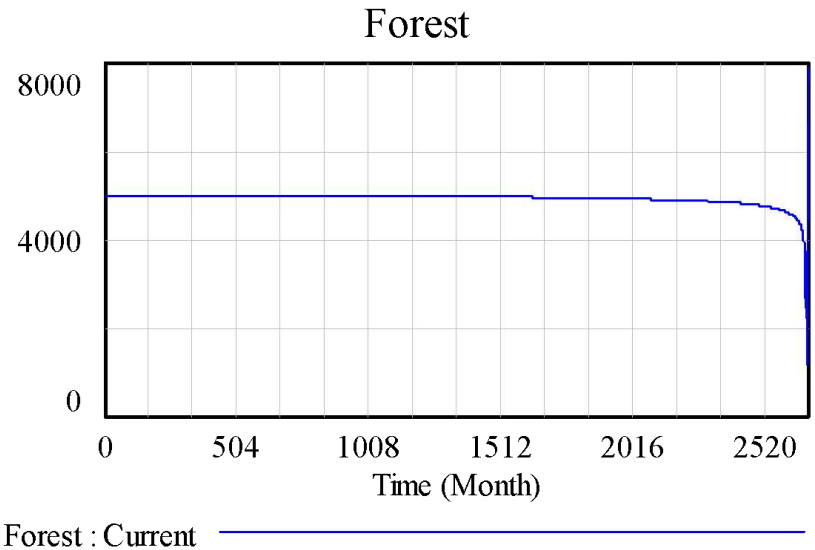
- Experiencing with S-Shaped growth with overshoot and collapse

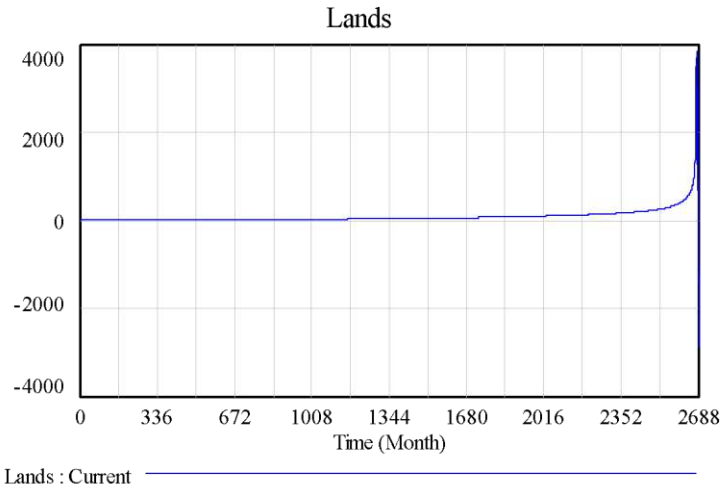
Source: Martın Garcıa, J. (2019).

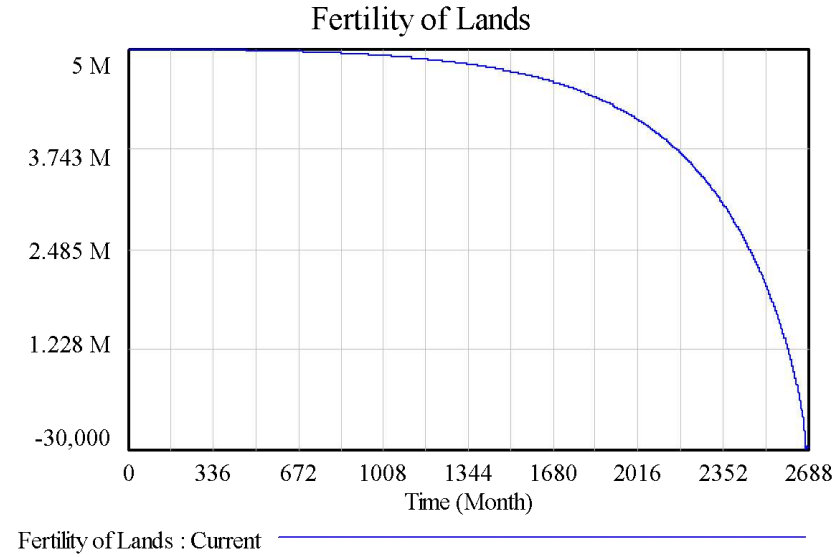


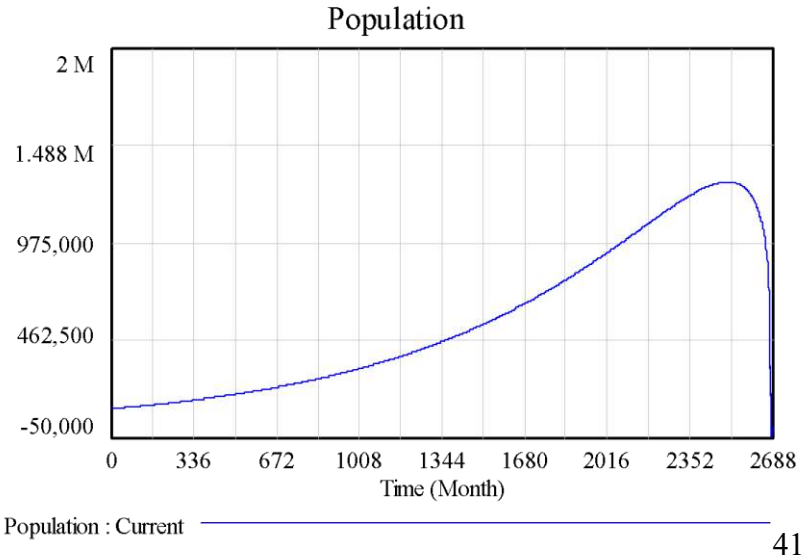
Simple examples of ST/SD for SusDev

- Experiencing with S-Shaped growth with overshoot and collapse









Simple examples of ST/SD for SusDev

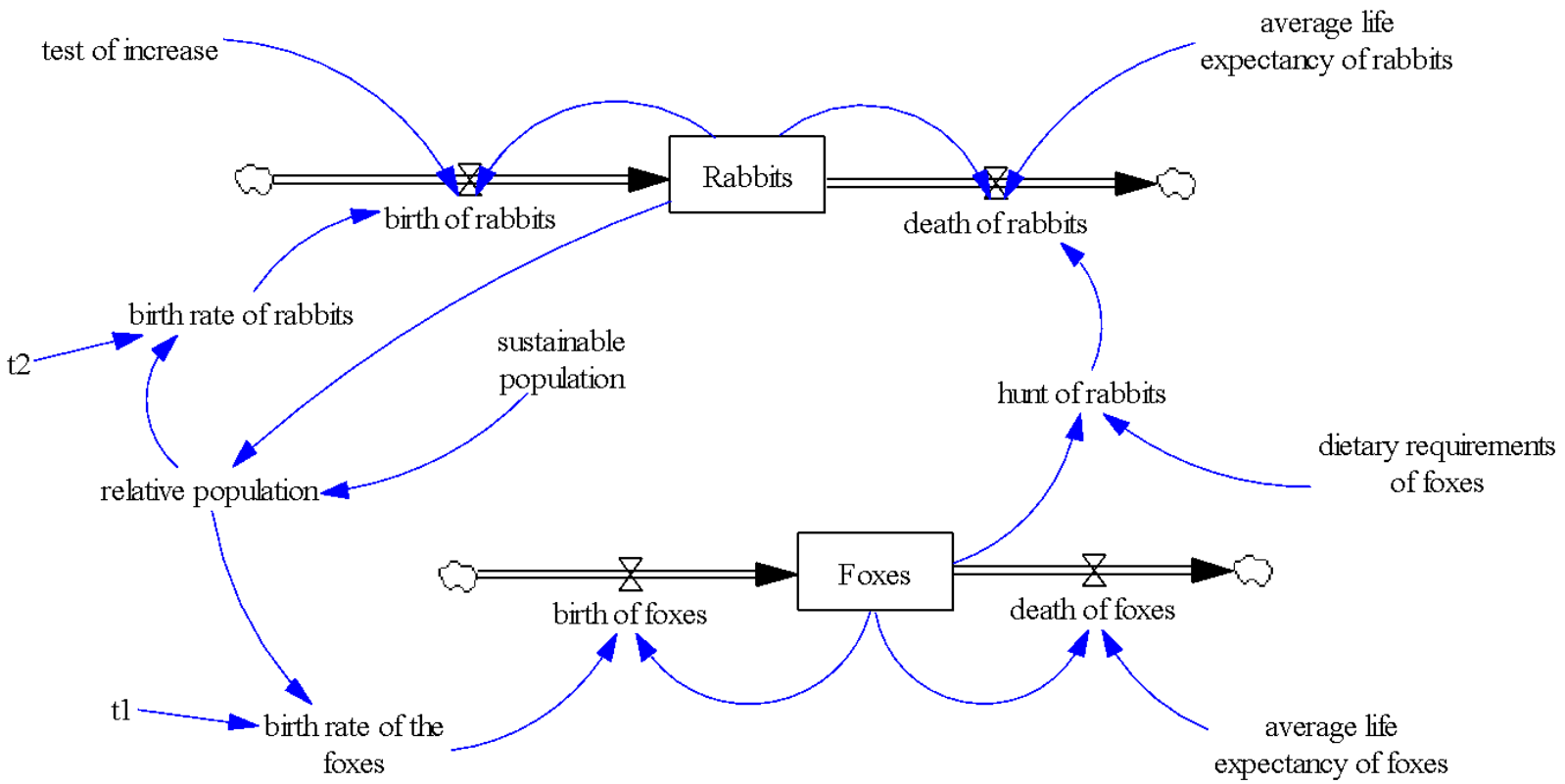
- Reflecting on S-Shaped Growth with Overshoot and Collapse

- Challenge your students to retrieve data and information about the Earth Overshoot Day (Global Footprint Network)
- https://www.footprintnetwork.org/our-work/earth-overshoot-day/

- What about 2021?
  - 29 July 2021

Simple examples of ST/SD for SusDev

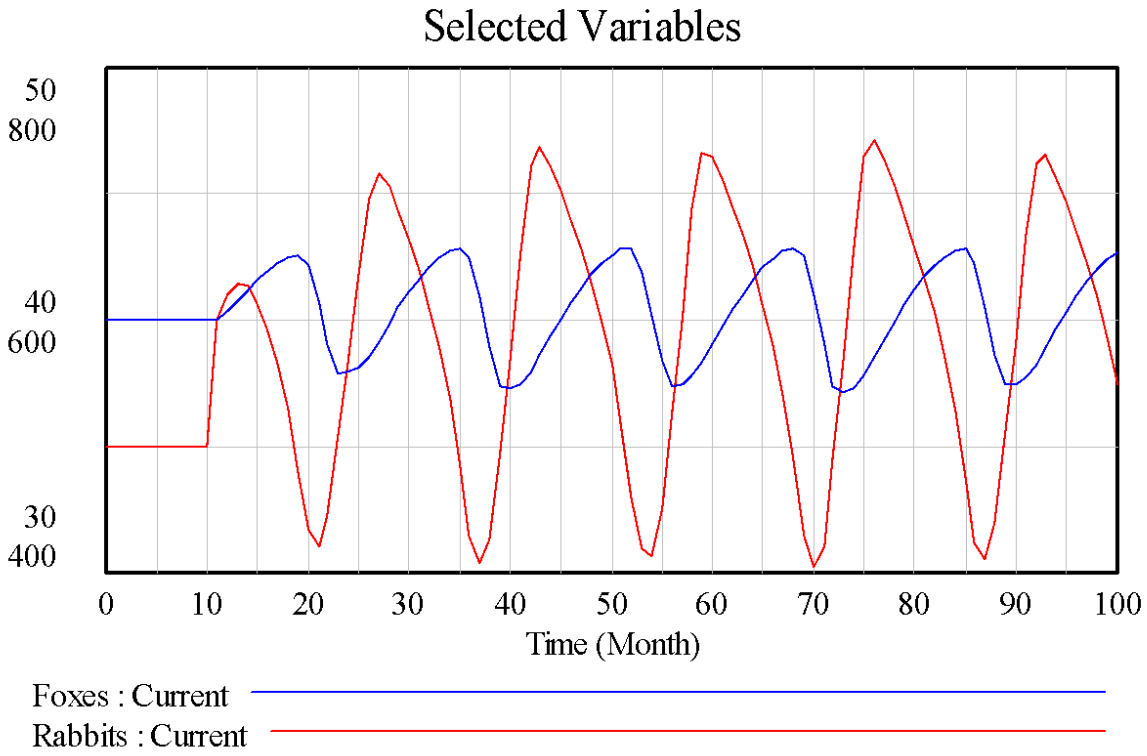
- **Oscillations**



Source: Martın Garcıa, J. (2019). *Theory and Practical Exercises of System Dynamics*; Lexington, KY.

Simple examples of ST/SD for SusDev

- **Oscillations**



Source: Martın Garcıa, J. (2019). *Theory and Practical Exercises of System Dynamics*; Lexington, KY.

ST/SD for SusDev: System Archetypes

System Archetypes

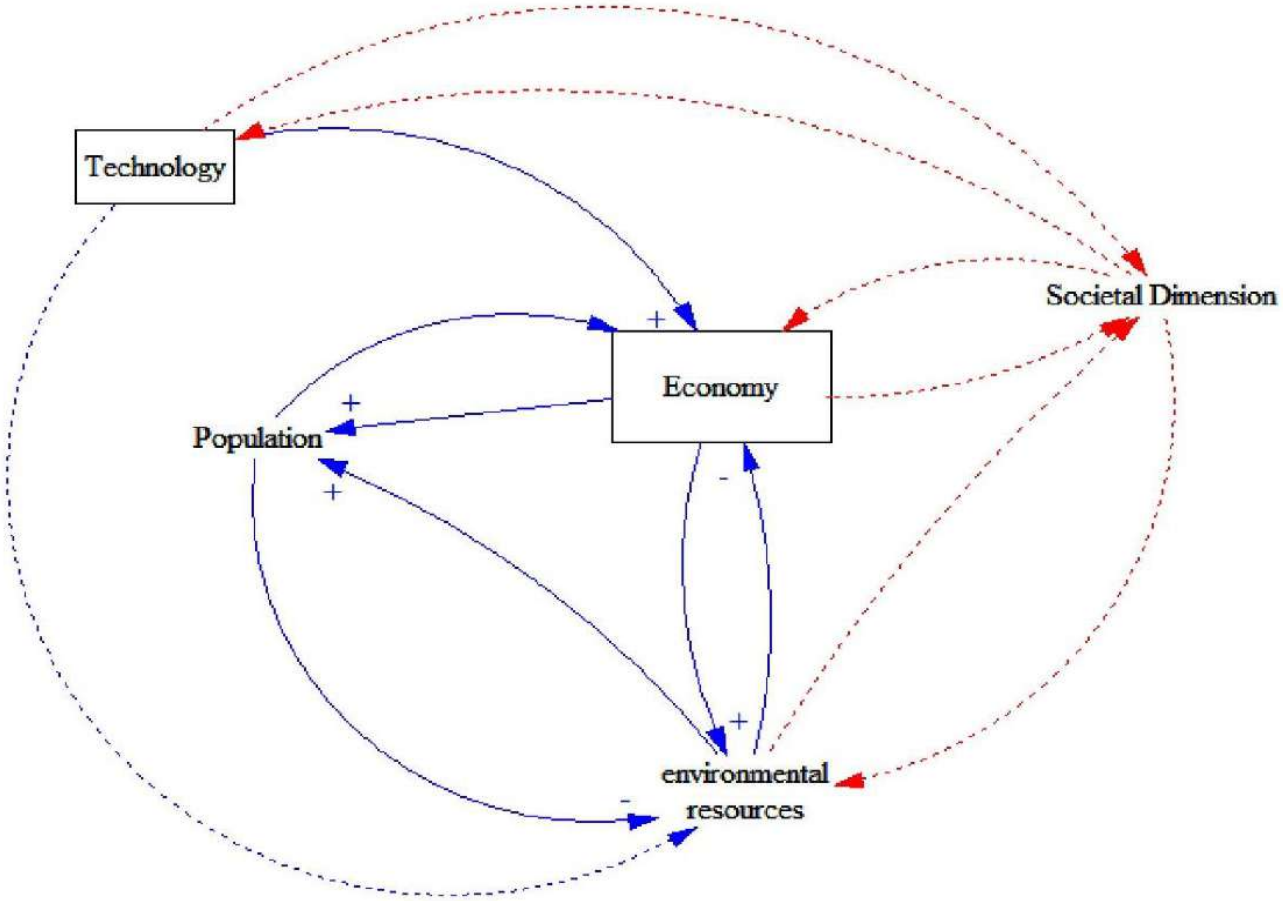
- Limits to growth
- Transfer (Solutions that fail)
- Shifting the burden
- Escalation
- Development and underinvestment
- Drifting goals
- Success to success
- …
- …
- Moving to **policy analysis**

ST/SD literature for SusDev

- A long tradition in the field of SD
  - Forrester (1971): World Dynamics
  - Meadows et al. (1972): Limits to Growth
    - (and updates)
  - Club of Rome
  - …
  - More recently: Ford, Saaed, Sterman, Rockstrom, Moxnes, Kopainsky, …

CLD of Sustainable Development dimensions

- Moving to **policy analysis**



From IO1 - SYSTEMA

SusDev and the UN Agenda 2030

- "Transforming our world": the 2030 Agenda for Sustainable Development (https://sdgs.un.org/2030agenda)
- The Agenda is "a plan of action for people, planet and prosperity. It also seeks to strengthen universal peace in larger freedom".
- **17 SDGs and 169 targets**
- The Goals and targets will stimulate action over the next fifteen years in areas of critical importance for humanity and the planet:
  - People
  - Planet
  - Prosperity
  - Peace
  - Partnership
- Several KPIs shared across the SDGs

The 17 Sustainable Development Goals (**SDGs**)

The 17 SDGs

SDG	Description
1 No poverty	End poverty in all its forms everywhere
2 Zero hunger	End hunger, achieve food security and improved nutrition and promote sustainable agriculture
3 Good health and well-being	Ensure healthy lives and promote well-being for all at all ages
4 Quality education	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
5 Gender equality	Achieve gender equality and empower all women and girls
6 Clean water and sanitation	Ensure availability and sustainable management of water and sanitation for all

The 17 SDGs

SDG	Description
7 Affordable and clean energy	Ensure access to affordable, reliable, sustainable and modern energy for all
8 Decent work and economic growth	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
9 Industry, innovation and infrastructure	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
10 Reduced inequalities	Reduce inequality within and among countries
11 Sustainable cities and communities	Make cities and human settlements inclusive, safe, resilient and sustainable

The 17 SDGs

SDG	Description
12 Responsible consumption and production	Ensure sustainable consumption and production patterns
13 Climate action	Take urgent action to combat climate change and its impacts
14 Life below water	Conserve and sustainably use the oceans, seas and marine resources for sustainable development
15 Life on land	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
16 Peace, justice and strong institutions	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
17 Partnerships for the goals	Strengthen the means of implementation and revitalize the global partnership for sustainable development

SDGs & KPIs

Goal: SDG 11 – *Sustainable Cities and Communities*

Target 11.1. By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums

Indicator 11.1.1: Proportion of urban population living in slums, informal settlements, or inadequate housing

Target 11.2. By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons

Indicator 11.2.1: Proportion of population that has convenient access to public transport, by sex, age and persons with disabilities

SDGs & KPIs

Goal: SDG 11 – *Sustainable Cities and Communities*

Target 11.3. By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries

Indicator 11.3.1: Ratio of land consumption rate to population growth rate

Indicator 11.3.2: Proportion of cities with a direct participation structure of civil society in urban planning and management that operate regularly and democratically

SDGs & KPIs

Goal: SDG 11 – *Sustainable Cities and Communities*

Target 11.4. Strengthen efforts to protect and safeguard the world's cultural and natural heritage

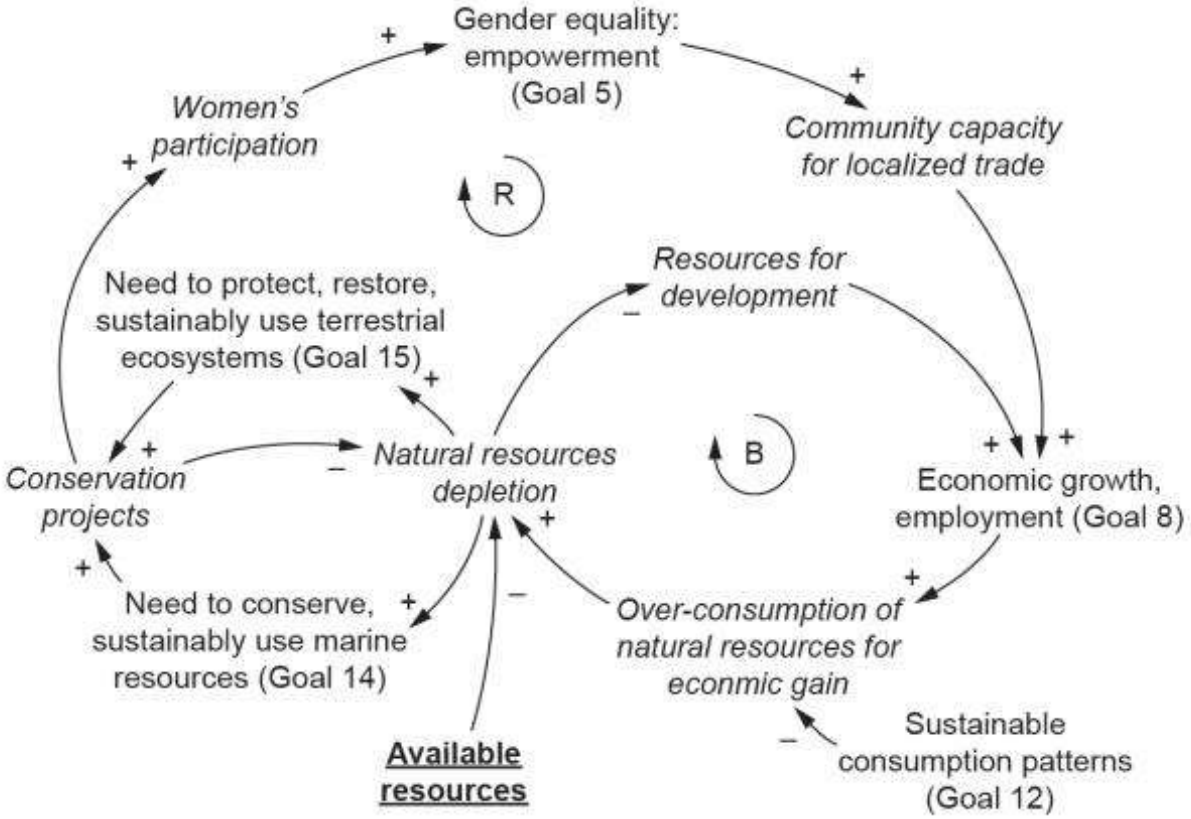
Indicator 11.4.1: Total expenditure (public and private) per capita spent on the preservation, protection and conservation of all cultural and natural heritage, by type of heritage (cultural, natural, mixed and World Heritage Centre designation), level of government (national, regional and local/municipal), type of expenditure (operating expenditure/investment) and type of private funding (donations in kind, private nonprofit sector and sponsorship)

Addressing the challenge of SDGs and the UN agenda 2030 with ST/SD

- Exploring complexity and interconnectedness
- The SDG interact one with the other (looking for nexus)
- Many measures are shared across various SDGs
- Synergies, nexus, trade-offs and delays are key factors
- Various levels: country level & universe level; governments & firms; policy-makers & citizens; etc.

ST/SD & SDGs: some examples

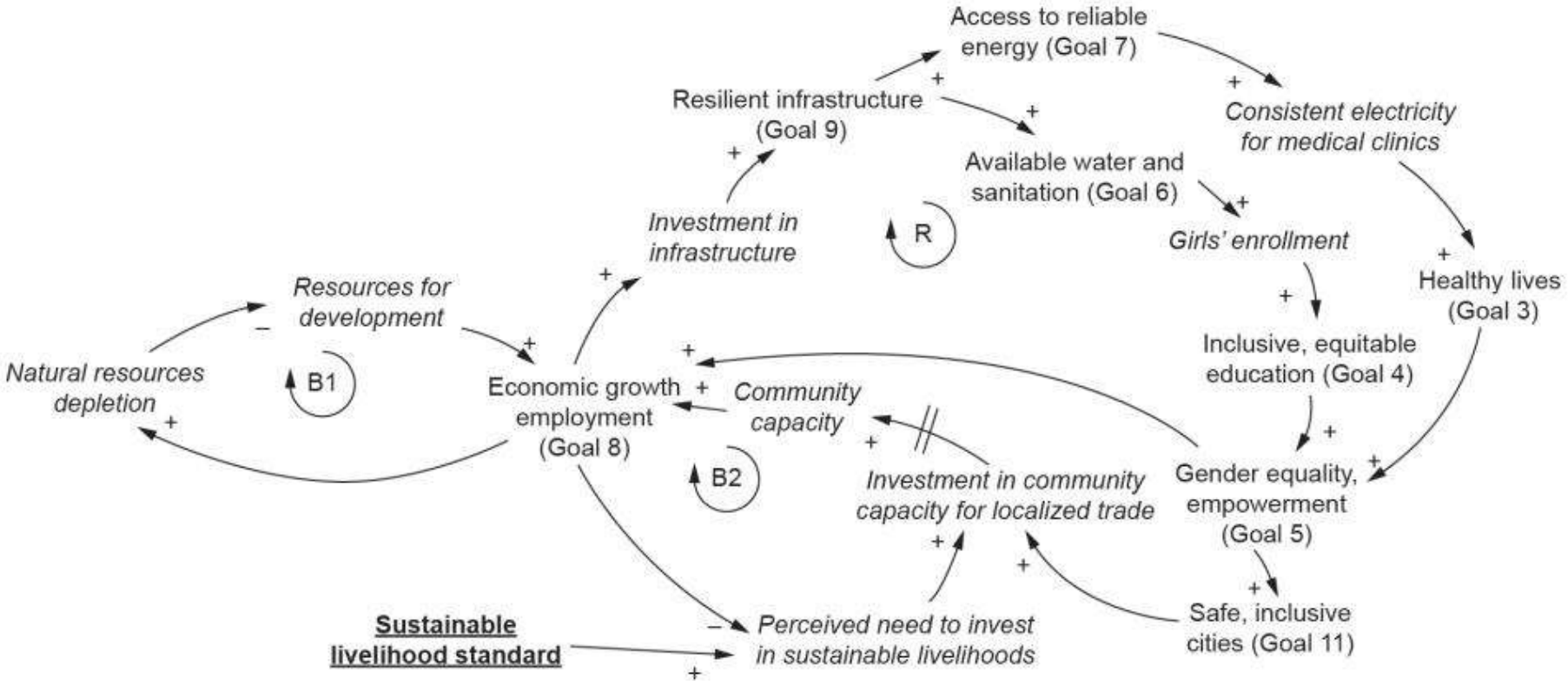
- Challenge: Spot in the CLD the «Limits to Growth» archetype and describe it



Source: Zhang, Q., Prouty, C., Zimmerman, J. B., & Mihelcic, J. R. (2016). More than target 6.3: a systems approach to rethinking sustainable development goals in a resource-scarce world. *Engineering*, *2*(4), 481-489.

ST/SD & SDGs: some examples

- Challenge: Spot in the CLD the «Growth and Underinvestment» archetype and describe it



Source: Zhang, Q., Prouty, C., Zimmerman, J. B., & Mihelcic, J. R. (2016). More than target 6.3: a systems approach to rethinking sustainable development goals in a resource-scarce world. *Engineering*, *2*(4), 481-489.

SD-based Interactive Learning Environments (ILES) and SusDev

- We usually refer to computer-based ILEs as environments:
  - where the interaction (Atkinson and Renkl, 2007) between a user (sometimes referred to as the «player» or the «learner») and the learning environment is primarily devoted to knowledge acquisition (i.e., learning, Kim, 1993),
  - specifically through an interactive process
  - whereby knowledge is created through the transformation of experience (so-called «experiential learning», Kolb, 1984; Kolb and Kolb, 2012).

System Dynamics ILEs ...

(Davidsen, 2000; Davidsen and Spector, 2015; Alessi and Kopainsky, 2015)

But also …

- Microworlds
  - Papert, 1980
  - Morecroft, 1988
- Virtual Worlds
  - Schön, 1983
- Learning Laboratories
- &
- Computer-Based Learning Environments
  - Senge and Sterman, 2000
  - Isaacs and Senge, 2000
- Management Flight Simulators
  - Sterman, 2000

See Maier and Grossler, 2000

SD-based ILEs for SusDev: examples

No.	Description	Link
1	Bass Model Experience	https://exchange.iseesystems.com/public/barnaf/bass-model-experience
2	Fish Banks FORIO/MIT	https://forio.com/simulate/mit/fishbanks/simulation/login.html
3	Fishery Simulation - ISEE Exchange by Erling Moxnes	https://exchange.iseesystems.com/public/erling/m302-fishery-simulator/index.html#page1
4	The COVID-19 Simulator (by ISEE systems)	https://exchange.iseesystems.com/public/isee/covid-19-simulator/index.html#page1
5	SUSTAIN Project ILE	https://exchange.iseesystems.com/public/ale25/sustain/index.html#page1
6	iSDG Millennium Institute	https://exchange.iseesystems.com/public/millenniuminstitute/isdg-20/index.html#page2

SusDev: the **Green Deal** (overview)

- Climate change and environmental degradation are an existential threat to Europe and the world.
- To overcome these challenges, the European Green Deal will transform the EU into a modern, resource-efficient and competitive economy, ensuring:
  - no net emissions of greenhouse gases by 2050
  - economic growth decoupled from resource use
  - no person and no place left behind

https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

SusDev: the **Green Deal** (benefits)

- The European Green Deal will improve the well-being and health of citizens and future generations by providing:
  - fresh air, clean water, healthy soil and biodiversity
  - renovated, energy efficient buildings
  - healthy and affordable food
  - more public transport
  - cleaner energy and cutting-edge clean technological innovation
  - longer lasting products that can be repaired, recycled and re-used
  - future-proof jobs and skills training for the transition
  - globally competitive and resilient industry

SusDev: the **Green Deal** (actions)

- Climate
- Energy
- Agriculture
- Industry
- Environment and oceans
- Transport
- Finance and regional development
- Research and innovation

SusDev: the **Green Deal** (challenges & ST/SD)

- Tip: discuss in class which challenges are raised by the Green Deal (*from a systemic perspective*)
  - Subsequently, discuss how and where ST/SD can provide an aid to policy analysis and action

ST/SD for SusDev - Discussion

ST/SD – Strengths and opportunities

- Describe a system (or, better, a problem) as a whole
- Highlight the dynamic nature and the interdependencies among the elements of the system
- Represent complexity (e.g., causality, non-linearity, delays, etc.) and circolarity
- Understand the relationship between structure and behavior
- Understand stocks-and-flows dynamics
- Spot and account for "side-effects"
- Favor policy modelling, decision-making, and understanding
- … and many others …

Looking ahead

- From Sustainable Development …
- To … Digital Transformation

- Digital Transformation can be defined as:
  - Increasing application of digitization and/or automation that has important impacts on structure or characteristics of individual work, internal processes, communication, infrastructure, business ecosystems and products/services for internal and/or external customers. The core of Digital Transformation is the overall digitization and cross-linking of the value creation process.

- **Lecture 4**

Looking ahead

SMEs need to embrace *Digital Transformation* in order to become sustainable.

Key factors for SMEs

a) An increasing trend to operate online

b) Use of Artificial Intelligence for tasks (like chatbots)

c) Increased use of social media

d) Increasing reliance on cloud technology (Viswanathan & Telukdarie, 2021)

This implies that SMEs need to:

- 1) Fundamentally change their business models
- 2) Digitize their operating models
- 3) Attract and retail people with the necessary, diverse skills to succeed in the Fourth Industrial Revolution
- 4) Develop new digital metrics of success

Digital Transformation can be a source of success and **Sustainable Development**

References

- List in the word file

Resources

- System Dynamics Society
  - https://www.systemdynamics.org/
- Italian Chapter of the System Dynamics Society
  - http://www.systemdynamics.it/new/
- Journals
  - System Dynamics Review
  - https://onlinelibrary.wiley.com/journal/10991727
  - Simulation&Gaming
  - https://journals.sagepub.com/home/sag
- Software
  - Vensim, Stella, Powersim, SYSDEA, Forio

Resources (MFSs)

No.	Description	Link
1	Bass Model Experience	https://exchange.iseesystems.com/public/barnaf/bass-model-experience
2	Fish Banks FORIO/MIT	https://forio.com/simulate/mit/fishbanks/simulation/login.html
3	Fishery Simulation - ISEE Exchange by Erling Moxnes	https://exchange.iseesystems.com/public/erling/m302-fishery-simulator/index.html#page1
4	The COVID-19 Simulator (by ISEE systems)	https://exchange.iseesystems.com/public/isee/covid-19-simulator/index.html#page1
5	SUSTAIN Project ILE	https://exchange.iseesystems.com/public/ale25/sustain/index.html#page1
6	iSDG Millennium Institute	https://exchange.iseesystems.com/public/millenniuminstitute/isdg-20/index.html#page2
7	FishILE	https://exchange.iseesystems.com/public/barnaf/fish-ile-3/index.html#page1

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https://www.linkedin.com/showcase/systema-project/?viewAsMember=true

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