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Transition towards sustainable and resilient food economies: how to intervene in complex systems

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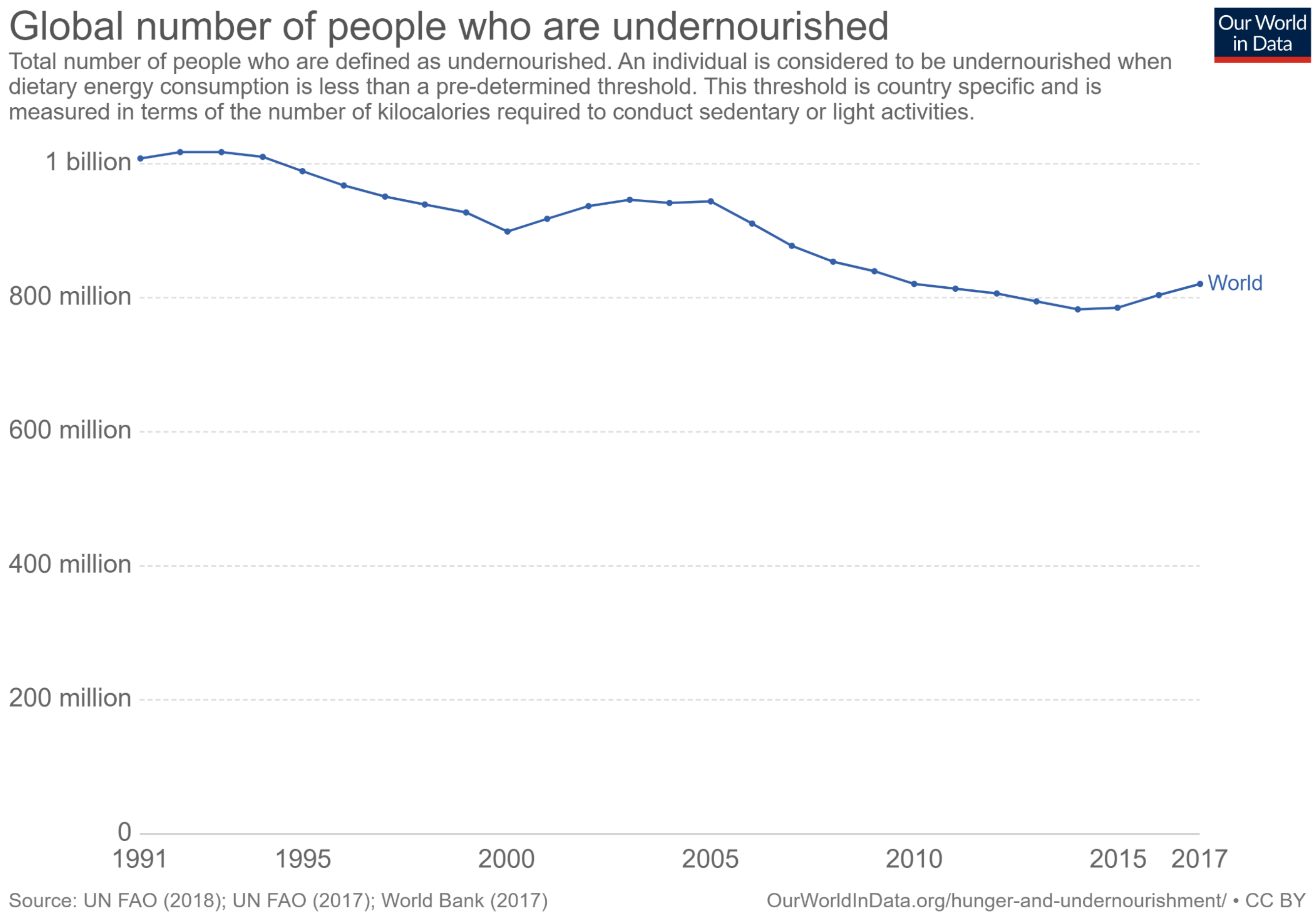
Overview

- Part 1: A systematic overview of challenges to and solutions for increasing the sustainability of the food system
- Part 2: The nature of complex systems
- Part 3: Food systems as complex food systems

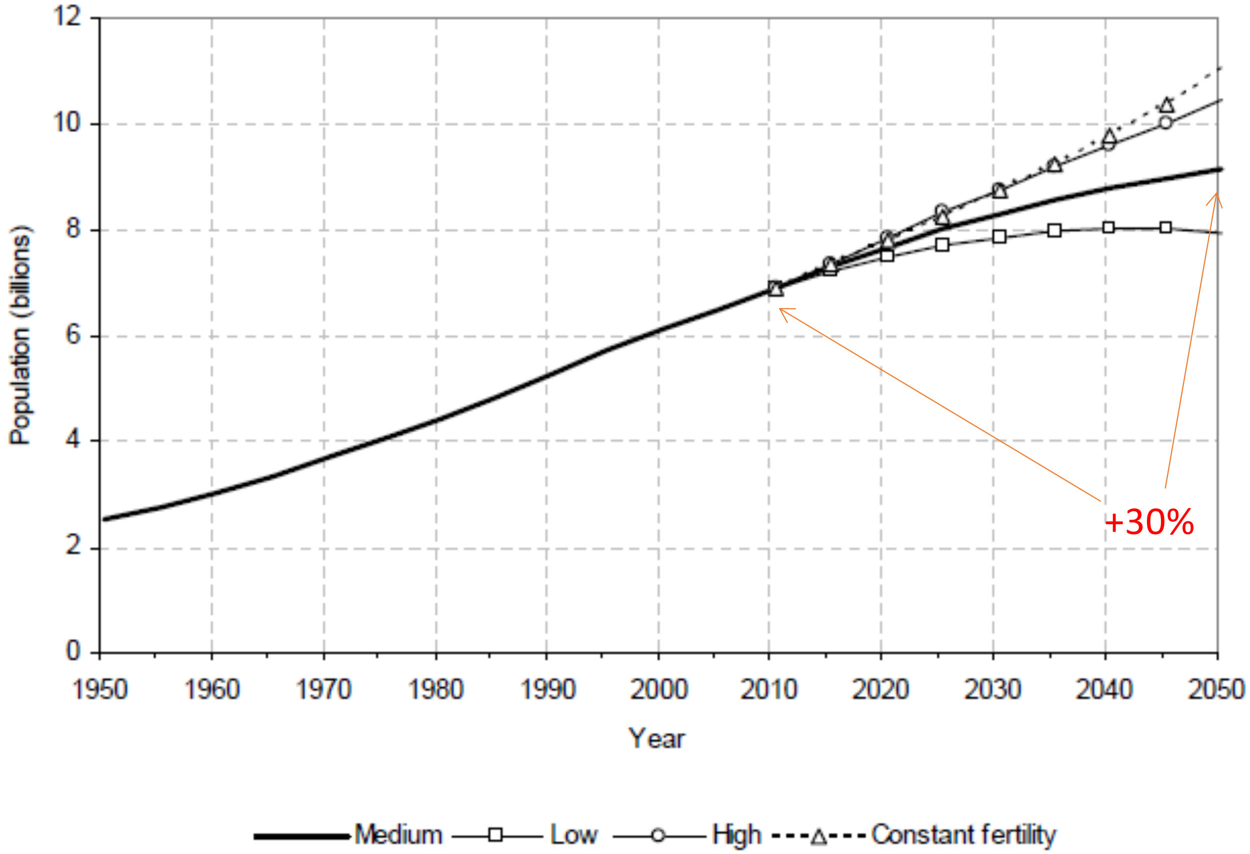
Part 1

A systematic overview of challenges to and solutions for increasing the sustainability of the food system

Almost 1 billion people undernourished today

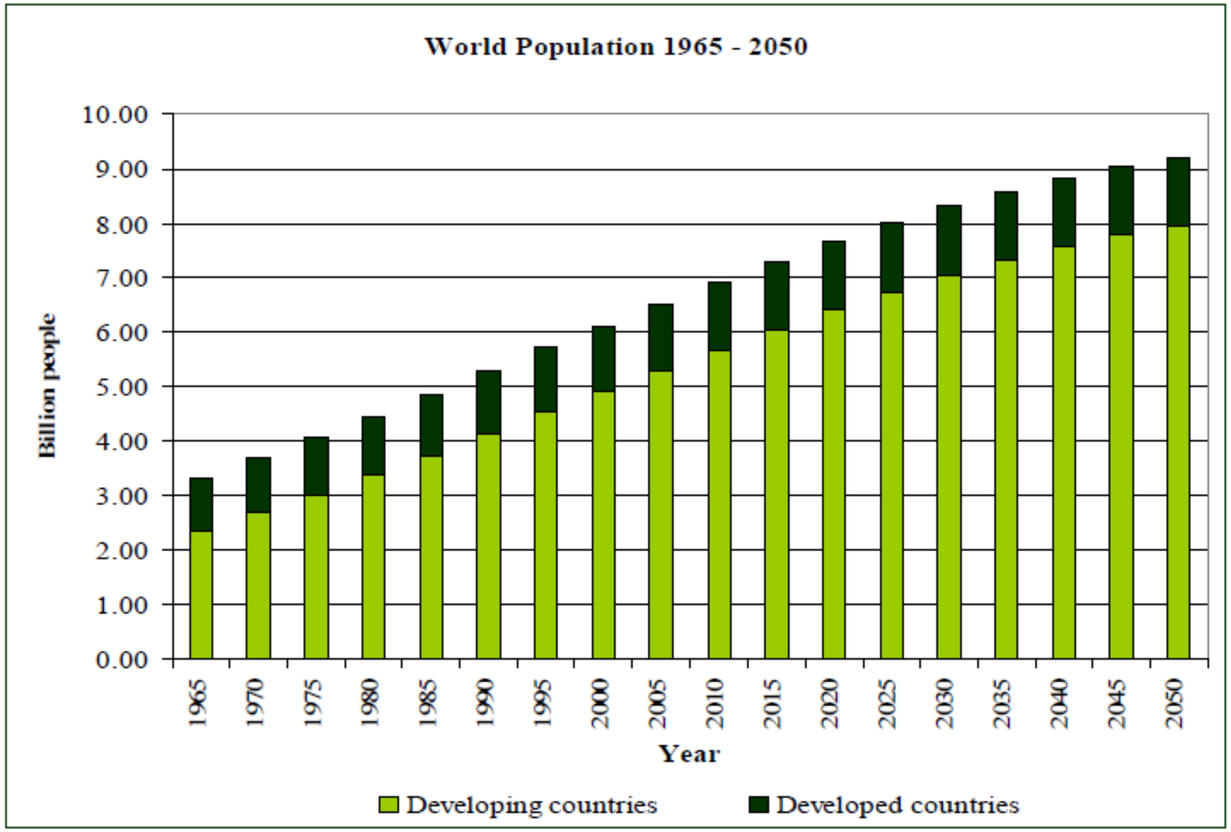


> 9 billion people expected in 2050…

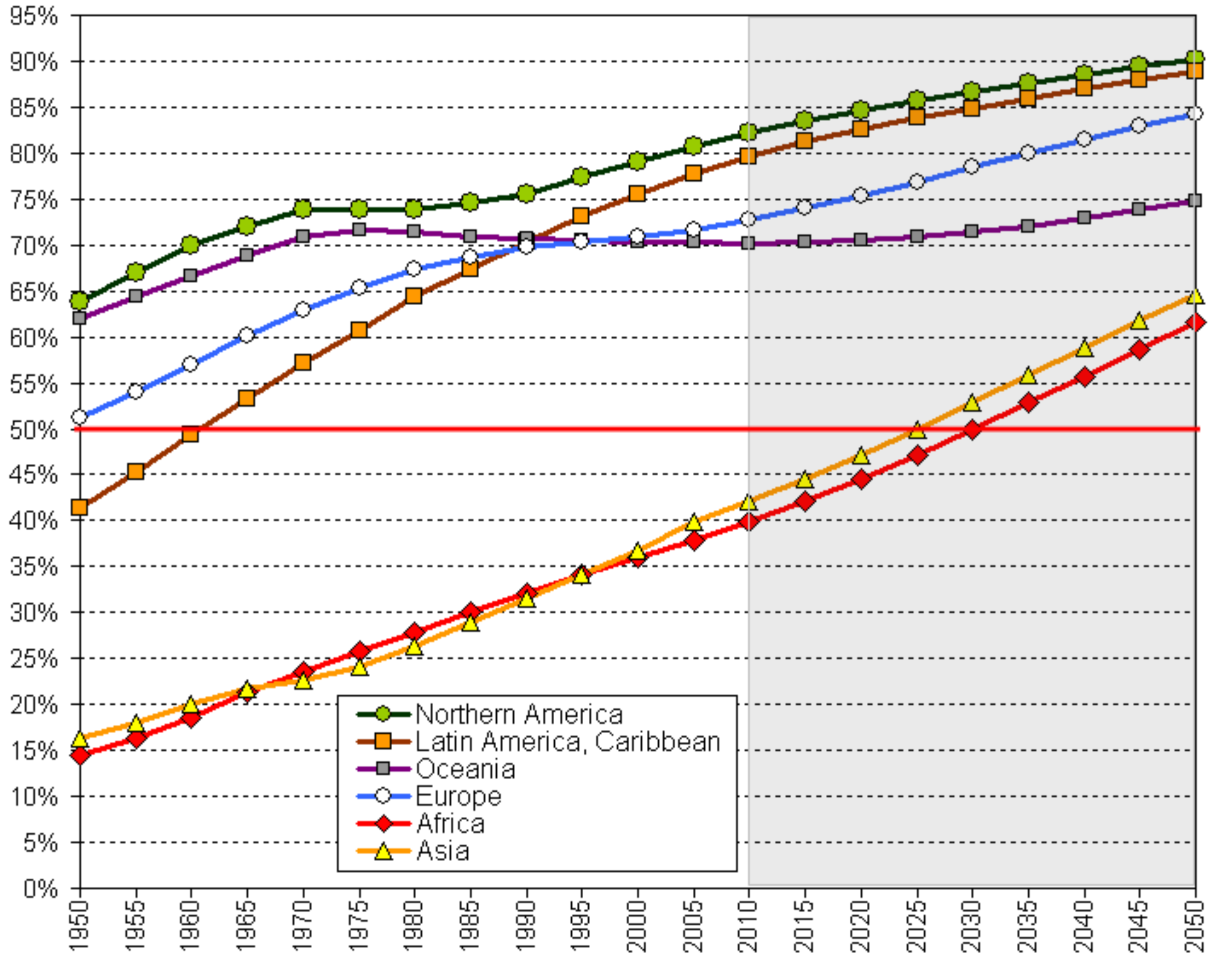


Source: Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat (2009). World Population Prospects: *The 2008 Revision*. New York: United Nations.

… primarily in developing countries!

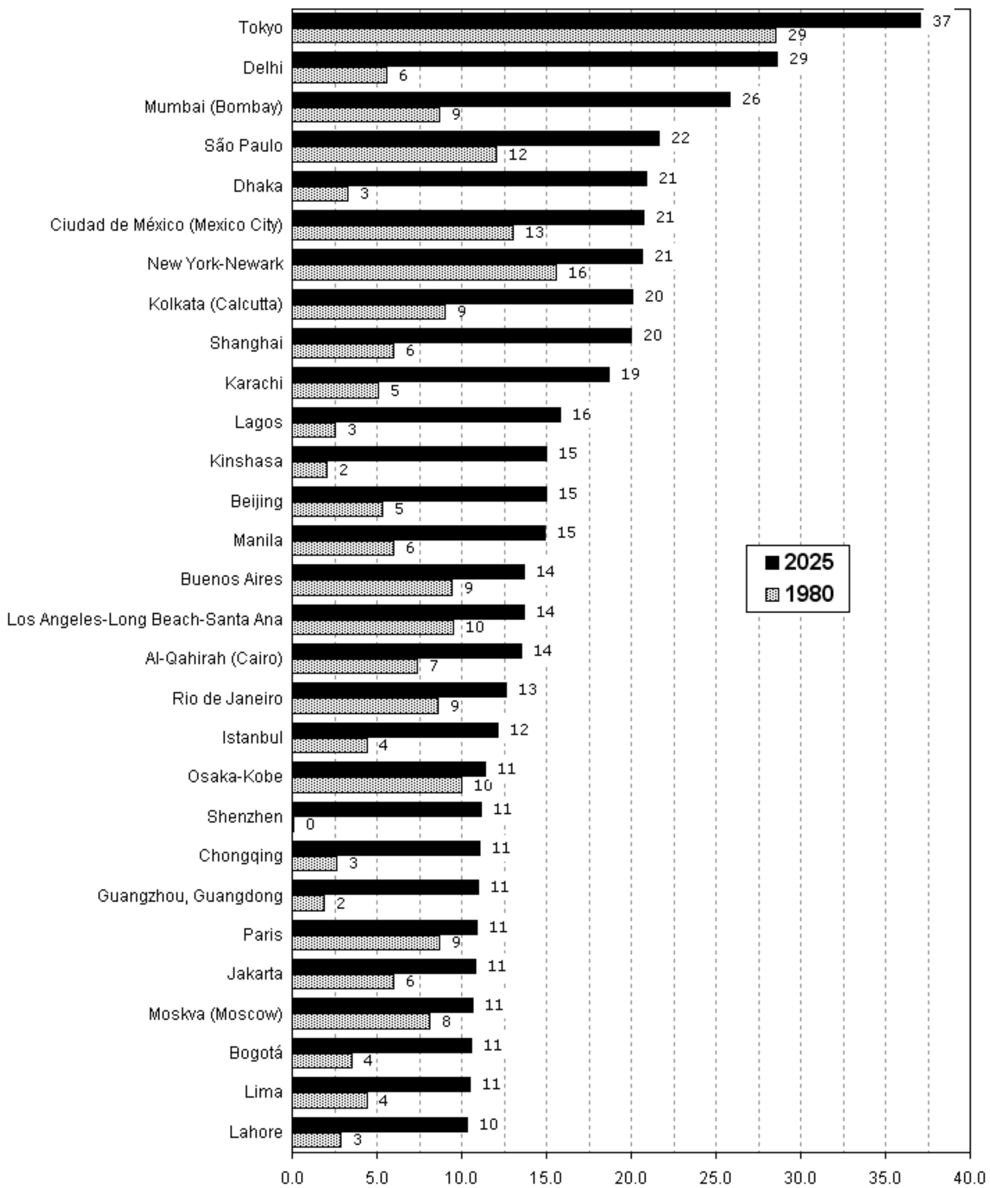


Source: Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat (2007)



Urban population as share of total population

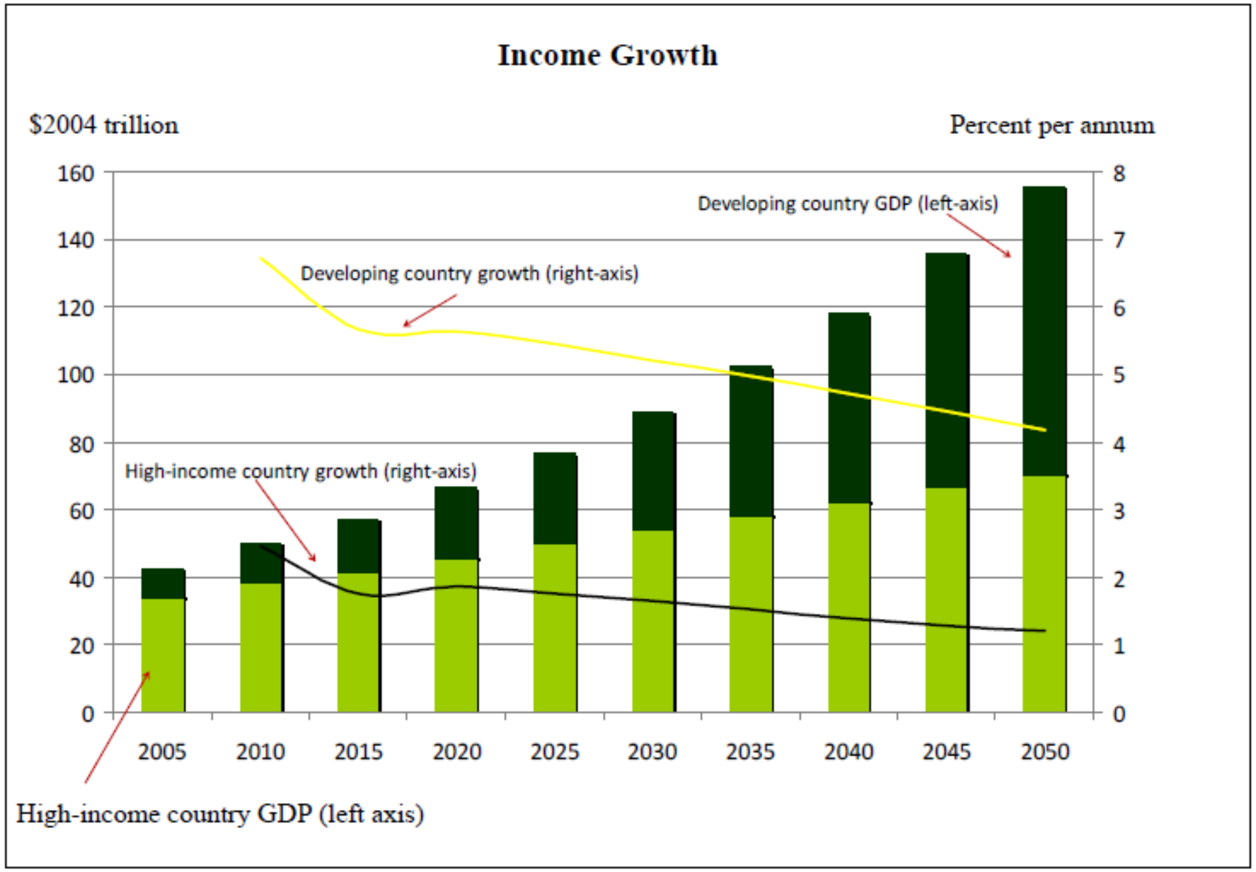
Source: United Nations, Department of Economic and Social Affairs, Population Division: *World Urbanization Prospects, the 2009 Revision*. New York, 2010



Population of the 29 urban agglomerations/ megacities

Source: United Nations, Department of Economic and Social Affairs, Population Division: *World Urbanization Prospects, the 2009 Revision*. New York, 2010

Expected income growth… again also in LDCs



Source: Mensbrugghe et al. (2009)

Table 1. Per capita food consumption (kcal per person per day). Reproduced with permission from Alexandratos (2006).

	1969/1971	1979/1981	1989/1991	1999/2001	2015	2030	2050
world	2411	2549	2704	2789	2950	3040	3130
developing countries	2111	2308	2520	2654	2860	2960	3070
sub-Saharan Africa	2100	2078	2106	2194	2420	2600	2830
Near East/North Africa	2382	2834	3011	2974	3080	3130	3190
Latin America and Carribean	2465	2698	2689	2836	2990	3120	3200
South Asia	2066	2084	2329	2392	2660	2790	2980
East Asia	2012	2317	2625	2872	3110	3190	3230
industrial countries	3046	3133	3292	3446	3480	3520	3540
transition countries	3323	3389	3280	2900	3030	3150	3270

Table 2. Calories from major commodities (kcal per capita per day) in developing, industrial countries and China. Data from: FAOSTAT (http://faostat.fao.org/site/368/Desktop.Default.aspx?PageID=368#ancor).

		meat	% change four decades	sugar	% change four decades	wheat	% change four decades	rice	% change four decades
developing	1963	147		75		245		580	
countries	1983	210		128		453		694	
	2003	369	119	170	127	457	87	655	13
industrial	1963	833		349		592		188	
countries	1983	929		337		559		145	
	2003	958	15	328	−6	627	6	153	−19
China	1963	90		18		194		637	
	1983	192		54		534		962	
	2003	644	349	73	305	448	131	790	24

		meat	% change four decades
developing countries	1963	147	
	1983	210	
	2003	369	119
industrial countries	1963	833	
	1983	929	
	2003	958	15
China	1963	90	
	1983	192	
	2003	644	349

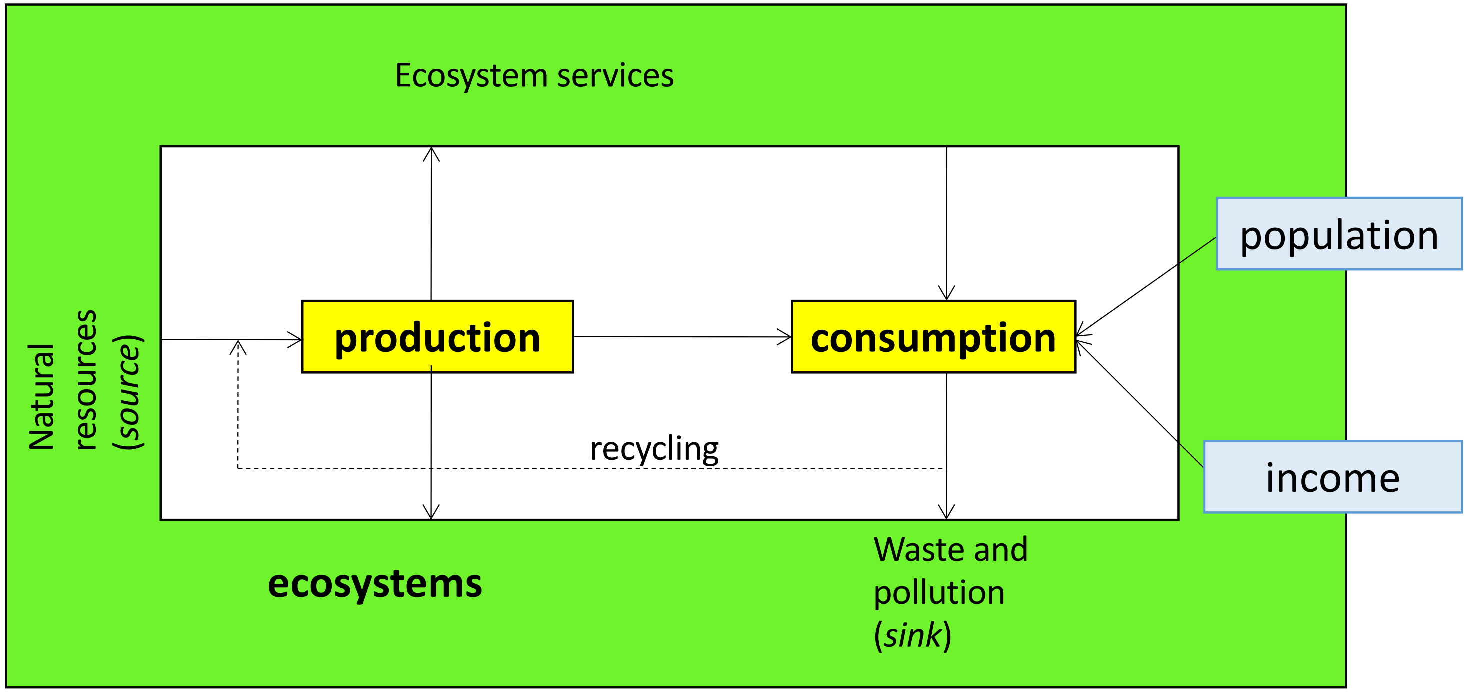
NUTRITION TRANSITION

Kearney, Phil. Trans. R. Soc. B, 2010

In summary…

- Almost one billion people hungry
- World population increases with 30% and will live primarily in megacities in the South (2050)
- Incomes rise and cause diet shift towards more meat and vegetable oils (nutrition transition) resulting in 60% increase in demand by 2050
- Natural resources such as oil, P, water and biodiversity become scarce (reinforced by climate change)
- Ecosystems are being destroyed such that essential ecosystem services are declining

I = P x A x T = population x affluence x technology = impact



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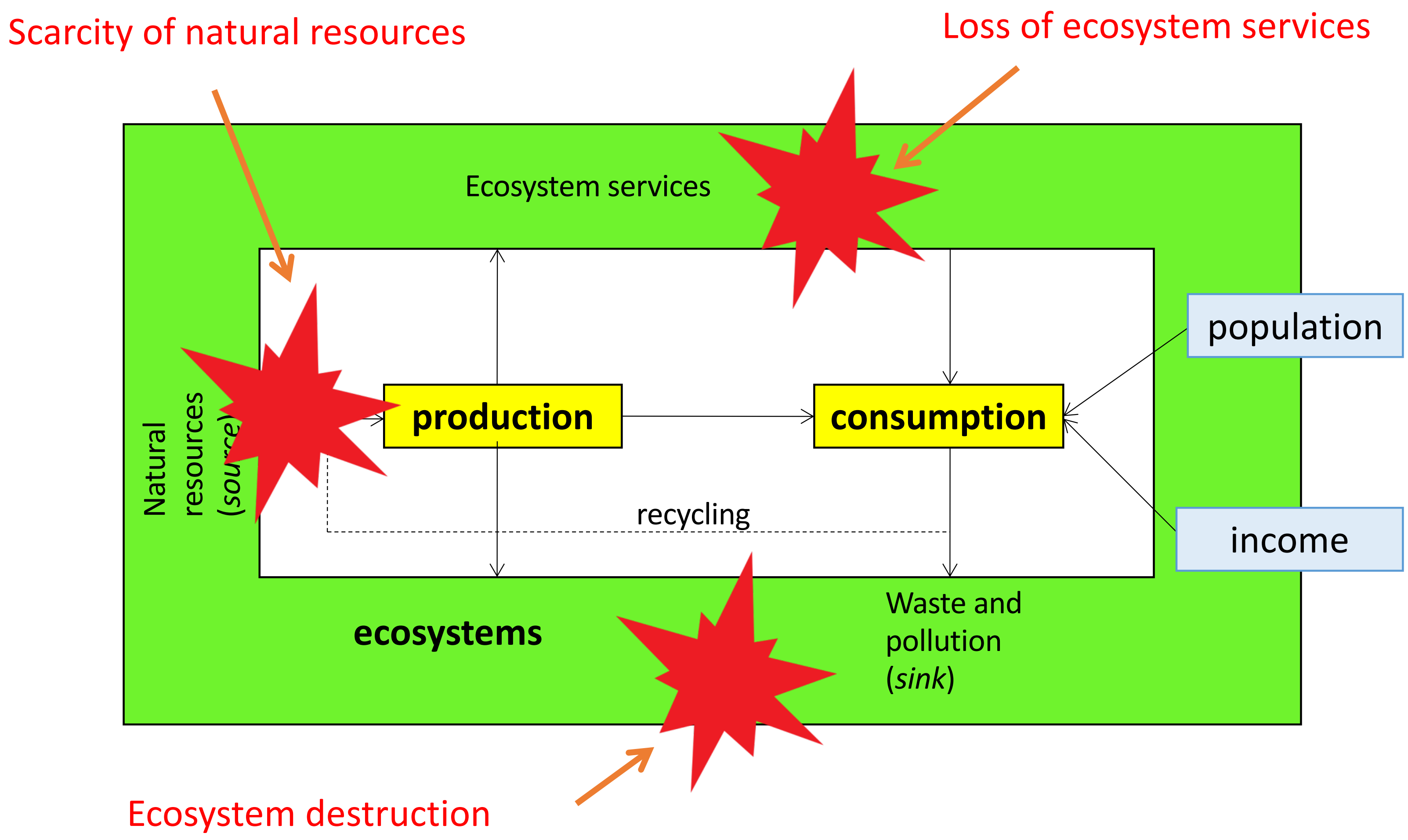

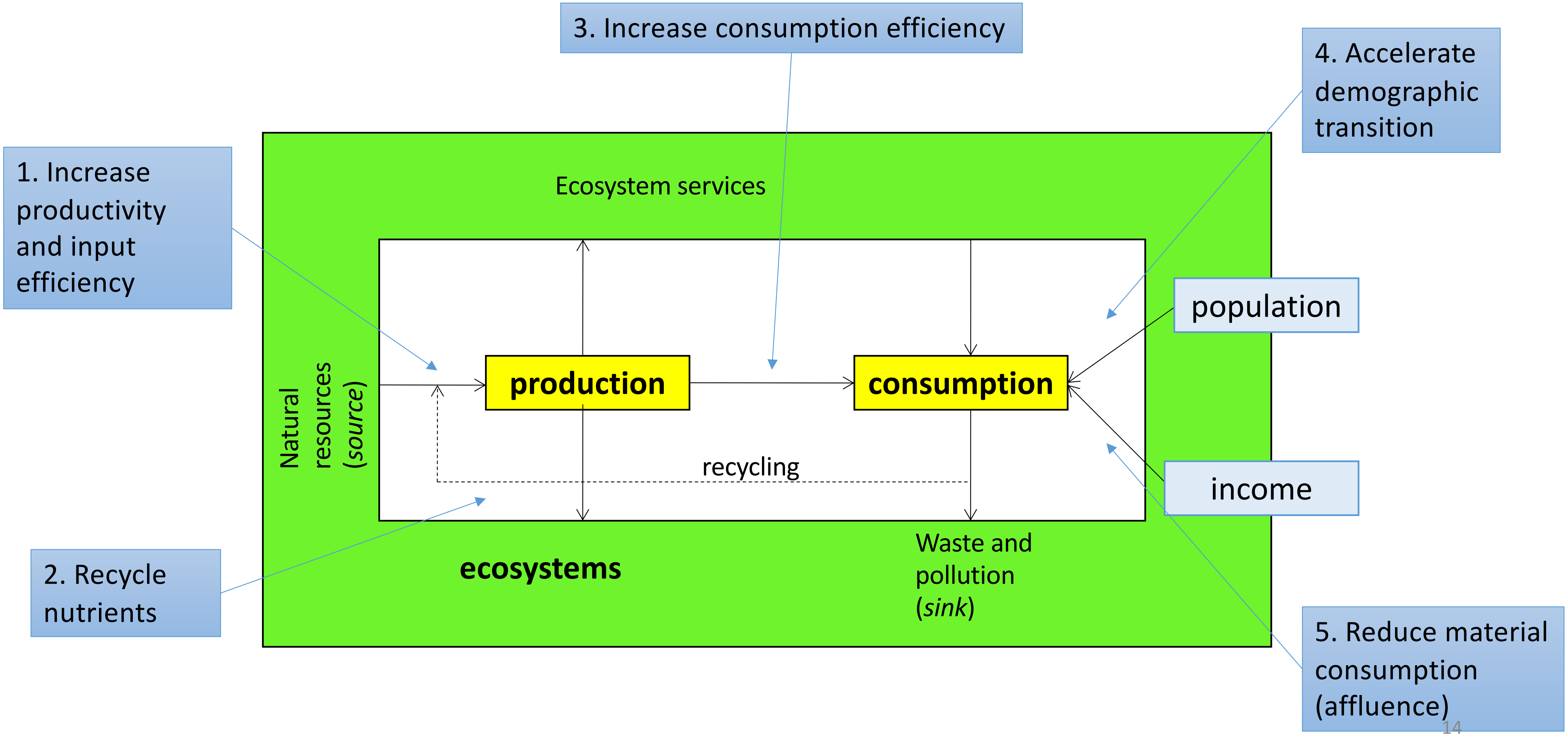
3. Increase consumption efficiency
4. Accelerate demographic transition
1. Increase productivity and input efficiency
Ecosystem services
population
production
consumption
Natural resources (source)
recycling
income
2. Recycle nutrients
ecosystems
Waste and pollution (sink)
5. Reduce material consumption (affluence)

FOOD SECURITY

REVIEW

Food Security: The Challenge of Feeding 9 Billion People

H. Charles J. Godfray,[1]* John R. Beddington,[2] Ian R. Crute,[3] Lawrence Haddad,[4] David Lawrence,[5] James F. Muir,[6] Jules Pretty,[7] Sherman Robinson,[8] Sandy M. Thomas,[9] Camilla Toulmin[10]

Continuing population and consumption growth will mean that the global demand for food will increase for at least another 40 years. Growing competition for land, water, and energy, in addition to the overexploitation of fisheries, will affect our ability to produce food, as will the urgent requirement to reduce the impact of the food system on the environment. The effects of climate change are a further threat. But the world can produce more food and can ensure that it is used more efficiently and equitably. A multifaceted and linked global strategy is needed to ensure sustainable and equitable food security, different components of which are explored here.

The past half-century has seen marked growth in food production, allowing for a dramatic decrease in the proportion of the world's people that are hungry, despite a doubling of the total population (Fig. 1) (1, 2). Nevertheless, more than one in seven people today still do not have access to sufficient protein and energy from their diet, and even more suffer from some form of micronutrient malnourishment (3). The world is now facing a new set of intersecting challenges (4). The global population will continue to grow, yet it is likely to plateau at some 9 billion people by roughly the middle of this century. A major correlate of this deceleration in population growth is increased wealth, and with higher purchasing power comes higher consumption and a greater demand for processed food, meat, dairy, and fish, all of which add pressure to the food supply system. At the same time, food producers are experiencing greater competition for land, water, and energy, and the need to curb the many negative effects of food production on the environment is becoming increasingly clear (5, 6). Overarching all of these issues is the threat of the effects of substantial climate change and concerns about how mitigation and adaptation measures may affect the food system (7, 8).

A threefold challenge now faces the world (9): Match the rapidly changing demand for food from a larger and more affluent population to its supply; do so in ways that are environmentally and socially sustainable; and ensure that the world's poorest people are no longer hungry. This challenge requires changes in the way food is produced, stored, processed, distributed, and accessed that are as radical as those that occurred during the 18th- and 19th-century Industrial and Agricultural Revolutions and the 20th-century Green Revolution. Increases in production will have an important part to play, but they will be constrained as never before by the finite resources provided by Earth's lands, oceans, and atmosphere (10).

Patterns in global food prices are indicators of trends in the availability of food, at least for those who can afford it and have access to world markets. Over the past century, gross food prices have generally fallen, leveling off in the past three decades but punctuated by price spikes such as that caused by the 1970s oil crisis. In mid-2008, there was an unexpected rapid rise in food prices, the cause of which is still being debated, that subsided when the world economy went into recession (11). However, many (but not all) commentators have predicted that this spike heralds a period of rising and more volatile food prices driven primarily by increased demand from rapidly developing countries, as well as by competition for resources from first-generation biofuels production (12). Increased food prices will stimulate greater investment in food production, but the critical importance of food to human well-being and also to social and political stability makes it likely that governments and other organizations will want to encourage food production beyond that driven by simple market mechanisms (13). The long-term nature of returns on investment for many aspects of food production and the importance of policies that promote sustainability and equity also argue against purely relying on market solutions.

So how can more food be produced sustainably? In the past, the primary solution to food shortages has been to bring more land into agriculture and to exploit new fish stocks. Yet over the past 5 decades, while grain production has more than doubled, the amount of land devoted to arable agriculture globally has increased by only ~9% (14). Some new land could be brought into cultivation, but the competition for land from other human activities makes this an increasingly unlikely and costly solution, particularly if protecting biodiversity and the public goods provided by natural ecosystems (for example, carbon storage in rainforest) are given higher priority (15). In recent decades, agricultural land that was formerly productive has been lost to urbanization and other human uses, as well as to desertification, salinization, soil erosion, and other consequences of unsustainable land

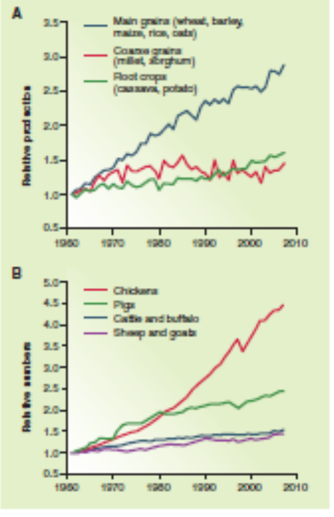

Fig. 1. Changes in the relative global production of crops and animals since 1961 (when relative production scaled to 1 in 1961). (**A**) Major crop plants and (**B**) major types of livestock. [Source: (2)]

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ANALYSIS

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Solutions for a cultivated planet

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Increasing population and consumption are placing unprecedented demands on agriculture and natural resources. Today, approximately a billion people are chronically malnourished while our agricultural systems are concurrently degrading land, water, biodiversity and climate on a global scale. To meet the world's future food security and sustainability needs, food production must grow substantially while, at the same time, agriculture's environmental footprint must shrink dramatically. Here we analyse solutions to this dilemma, showing that tremendous progress could be made by halting agricultural expansion, closing 'yield gaps' on underperforming lands, increasing cropping efficiency, shifting diets and reducing waste. Together, these strategies could double food production while greatly reducing the environmental impacts of agriculture.

Contemporary agriculture faces enormous challenges[1–3]. Even with recent productivity gains, roughly one in seven people lack access to food or are chronically malnourished, stemming from continued poverty and mounting food prices[4,5]. Unfortunately, the situation may worsen as food prices experience shocks from market speculation, bioenergy crop expansion and climatic disturbances[6,7]. Even if we solve these food access challenges, much more crop production will probably be needed to guarantee future food security. Recent studies suggest that production would need to roughly double to keep pace with projected demands from population growth, dietary changes (especially meat consumption), and increasing bioenergy use[1–4,8,9], unless there are dramatic changes in agricultural consumption patterns.

Compounding this challenge, agriculture must also address tremendous environmental concerns. Agriculture is now a dominant force behind many environmental threats, including climate change, biodiversity loss and degradation of land and freshwater[10–12]. In fact, agriculture is a major force driving the environment beyond the "planetary boundaries" of ref. 13.

Looking forward, we face one of the greatest challenges of the twenty-first century: meeting society's growing food needs while simultaneously reducing agriculture's environmental harm. Here we consider several promising solutions to this grand challenge. Using new geospatial data and models, we evaluate how new approaches to agriculture could benefit both food production and environmental sustainability. Our analysis focuses on the agronomic and environmental aspects of these challenges, and leaves a richer discussion of associated social, economic and cultural issues to future work.

The state of global agriculture

Until recently, the scientific community could not measure, monitor and analyse the agriculture–food–environment system's complex linkages at the global scale. Today, however, we have new data that characterize worldwide patterns and trends in agriculture and the environment[14–17].

Agricultural extent

According to the Food and Agriculture Organization (FAO) of the United Nations, croplands cover 1.53 billion hectares (about 12% of Earth's ice-free land), while pastures cover another 3.38 billion hectares (about 26% of Earth's ice-free land) (Supplementary Fig. 1). Altogether, agriculture occupies about 38% of Earth's terrestrial surface—the largest use of land on the planet[14,18]. These areas comprise the land best suited for farming[19]: much of the rest is covered by deserts, mountains, tundra, cities, ecological reserves and other lands unsuitable for agriculture[20].

Between 1985 and 2005 the world's croplands and pastures expanded by 154 million hectares (about 3%). But this slow net increase includes significant expansion in some areas (the tropics), as well as little change or a decrease in others (the temperate zone[21]; Supplementary Table 1). The result is a net redistribution of agricultural land towards the tropics, with implications for food production, food security and the environment.

Crop yields

Global crop production has increased substantially in recent decades. Studies of common crop groups (including cereals, oilseeds, fruits and vegetables) suggest that crop production increased by 47% between 1985 and 2005 (ref. 18). However, considering all 174 crops tracked by the UN FAO and ref. 15, we find global crop production increased by only 28% during that time[22].

This 28% gain in production occurred as cropland area increased by only 2.4%, suggesting a 25% increase in yield. However, cropland area that was harvested increased by about 7% between 1985 and 2005—nearly three times the change in cropland area, owing to increased multiple cropping, fewer crop failures, and less land left fallow. Accounting for the increase in harvested land, average global crop yields increased by only 20% between 1985 and 2005, substantially less than the often-cited 47% production increase for selected crop groups. (Using the same methods as for the 20% result, we note that yields increased by 56% between 1965 and 1985, indicating that yields are now rising less quickly than before.)

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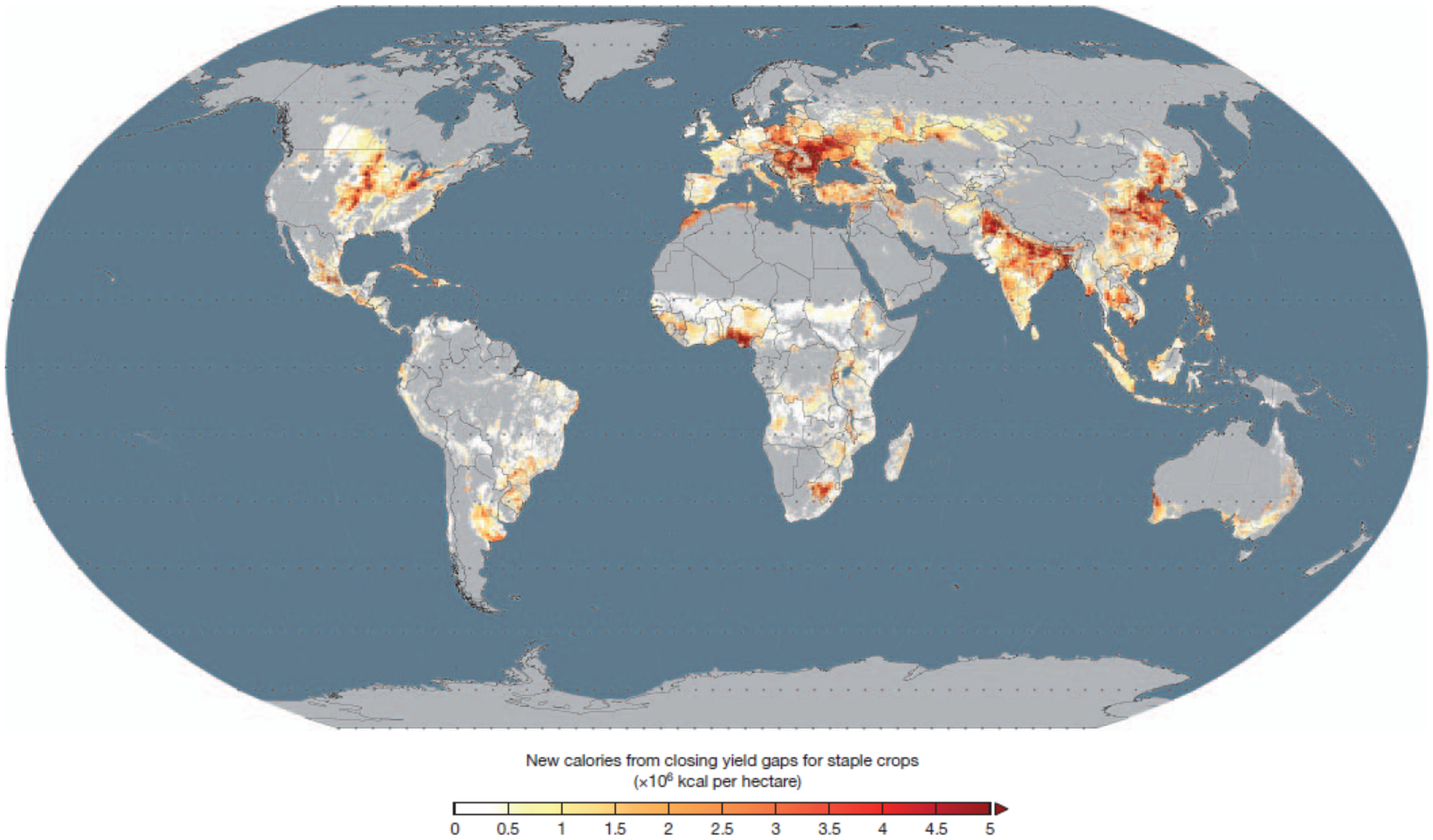
1. Increase productivity and input efficiency

- Close yield gap by better use of inputs (precision farming)
- Increase production limits and input efficiency by crop improvement (conventional or GM)
- Reduce yield losses
- Use less external resources (agro-ecology), but no expansion of agriculture

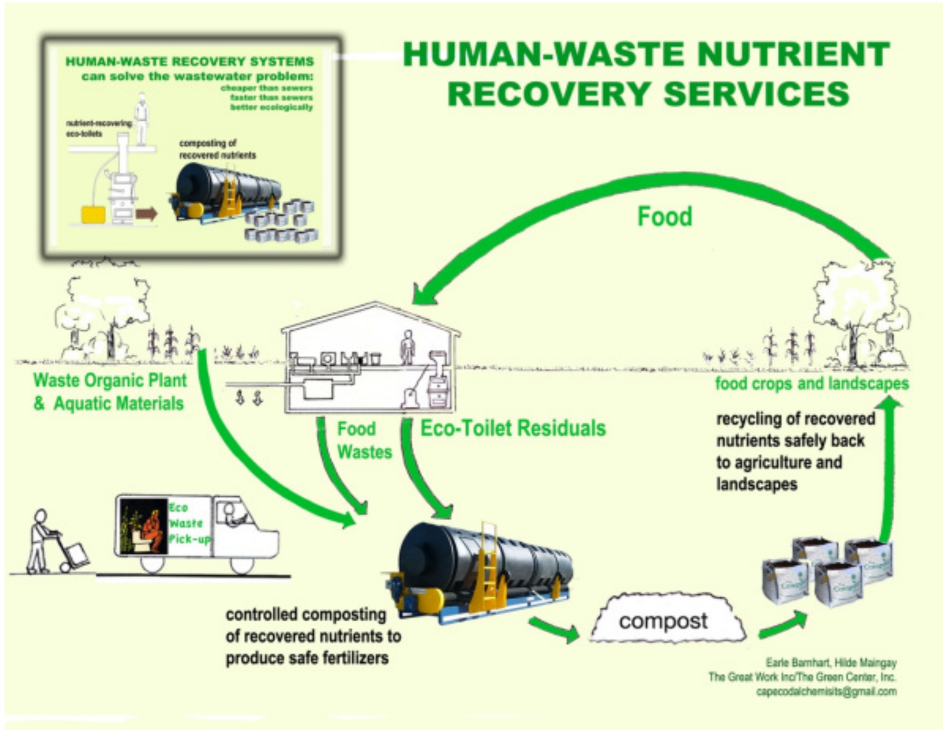
Achieving 95% of the yield potential would increase the amount of calories with 58% (Foley et al., Nature, 2011, 478:337-342)



2. Recycling nutrients

- Within the agroecosystem:
  - Improve soils
  - Compost
  - Manure

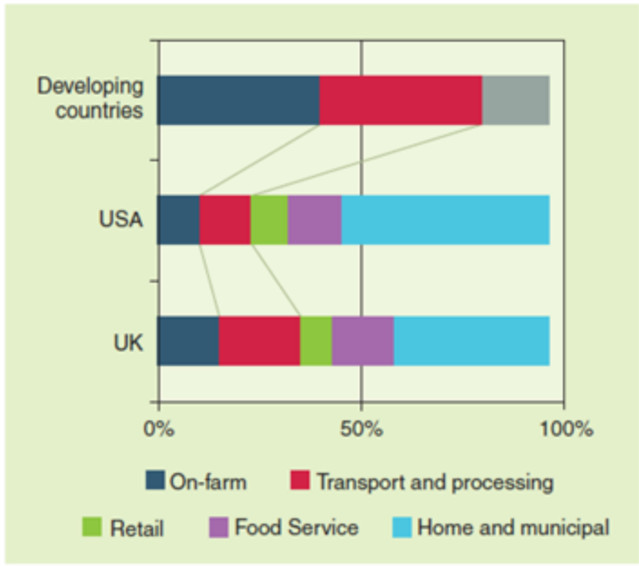
- Outside of the agroecosystem:
  - Food industry
  - Energy
  - Pharma
  - …



https://capecodecotoiletcenter.com/nutrient-recycling/

3. Increase consumption efficiency

- Reduce food waste
  - Low price of food
  - 10% of income spent on food
- Change diet composition towards health recommendations:
  - Less meat (100 g per day)
  - Less sugar (high energy dense food)
  - More vegetables and fruit



Food losses (Charles et al., 2010)

The production of 1 kg beef requires 5-7 kg cereals and 15.000 liters water.

TSJAAD: $1 / week

AUSTRALIË: $377 / week

Bron: TIME, 2016, Hungry Planet: What the World Eats, time.com

4. Accelerate demographic transition

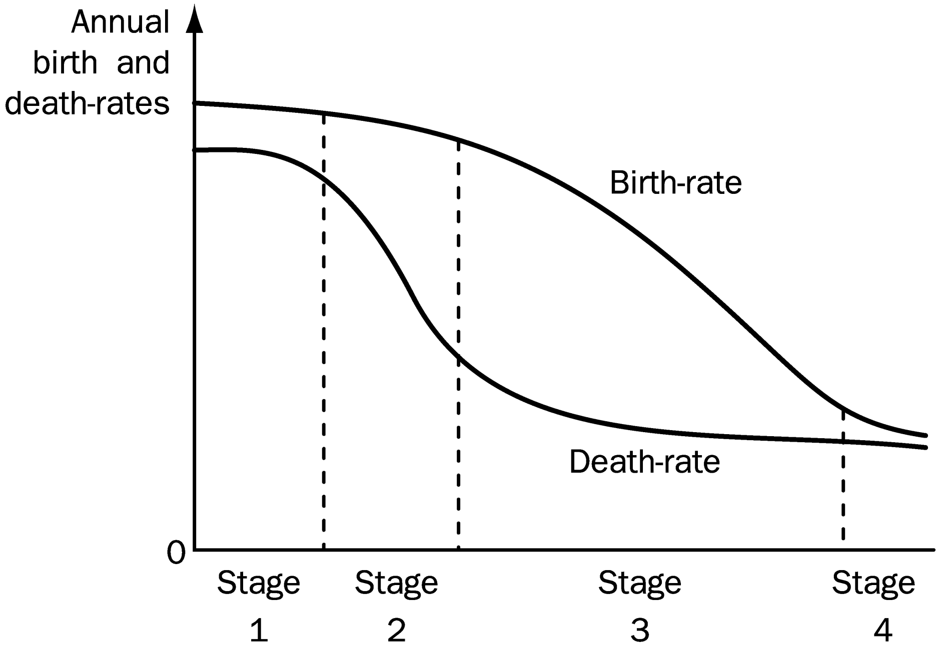


Figure 2.6 The theory of demographic transition

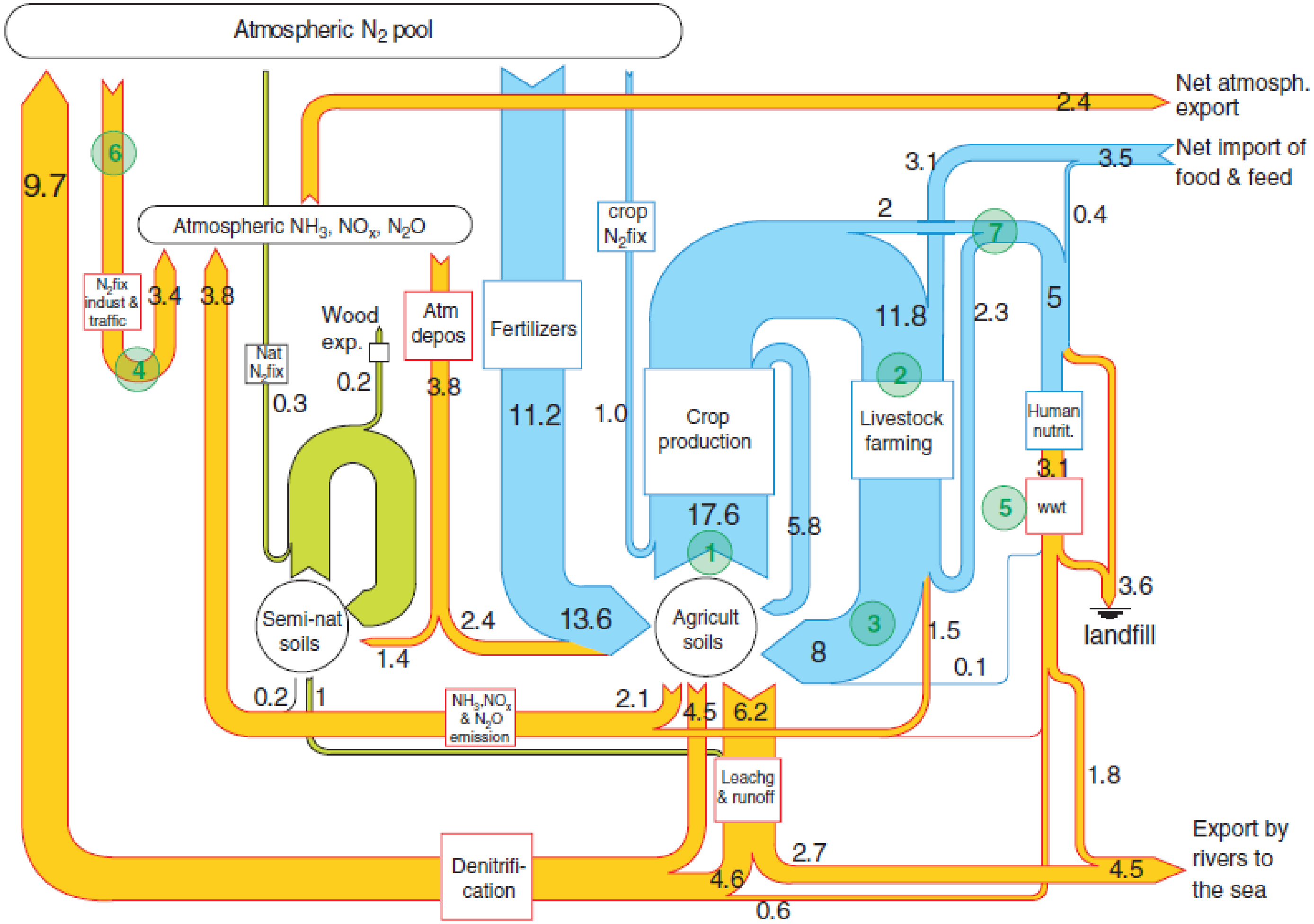
Source: Perman et al., 2003

- Education
- Economic development
- Rol and status of women

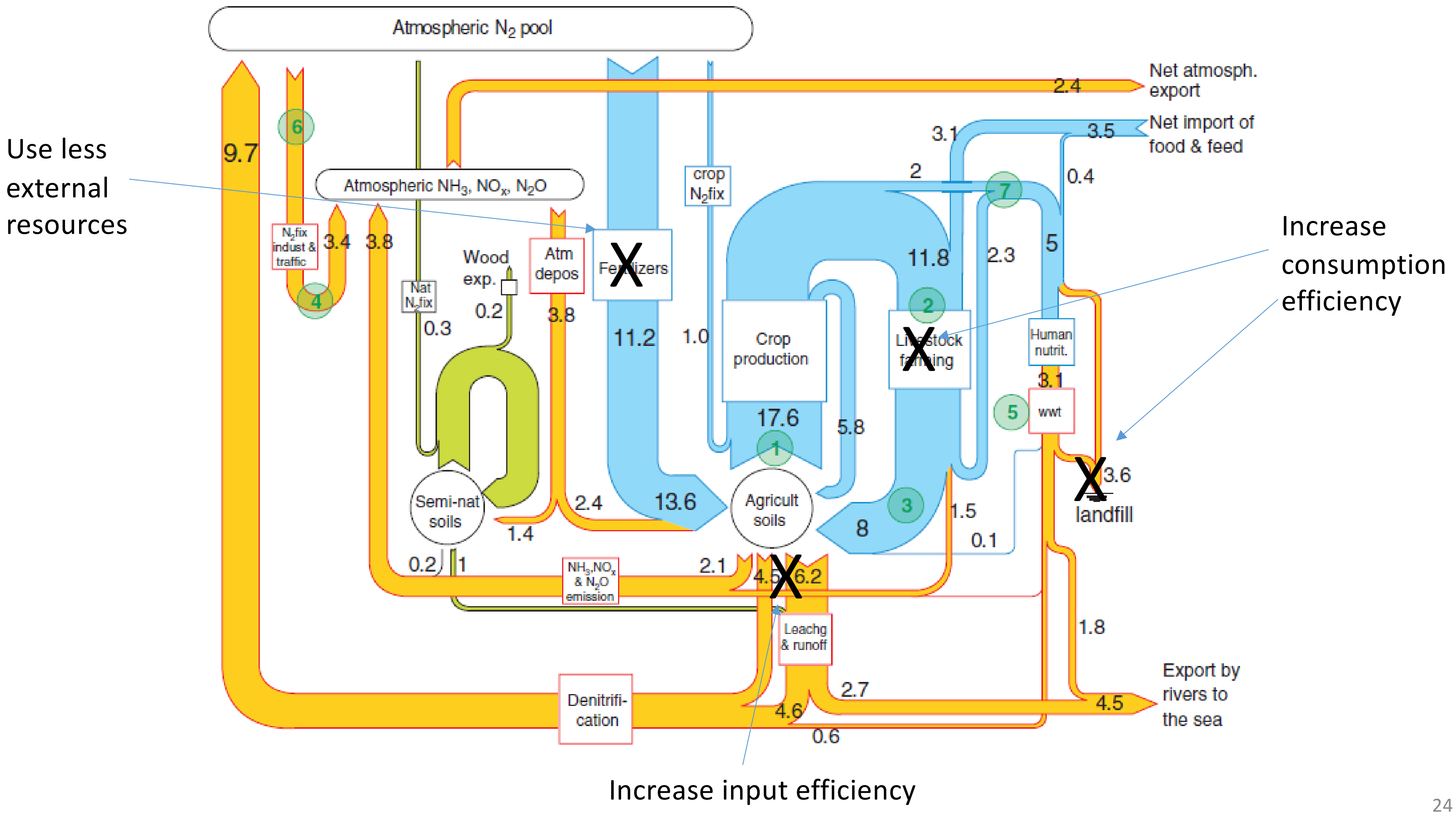
5. Reduce material consumption

- Dematerialisation not possible for food as services cannot be separated from product
- No crops for biofuels
- Sufficiency: decrease consumption to real needs
  - Consume less on a voluntary basis
  - Rationing
  - Financial instruments (e.g. fat tax)

Sutton et al., 2011. The European Nitrogen Assessment



Sutton et al., 2011. The European Nitrogen Assessment



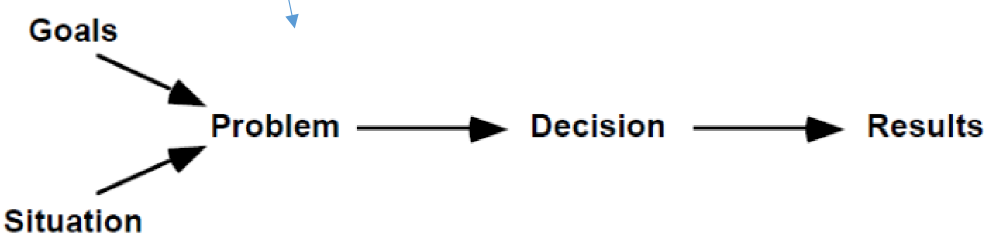
Part 2

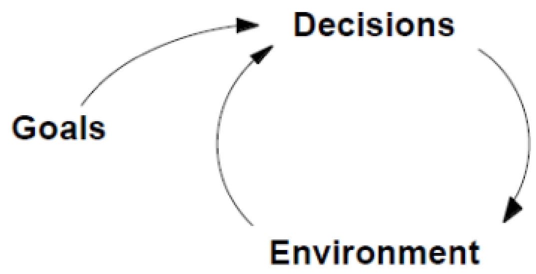
The nature of complex systems

Dynamic complexity arises because systems are

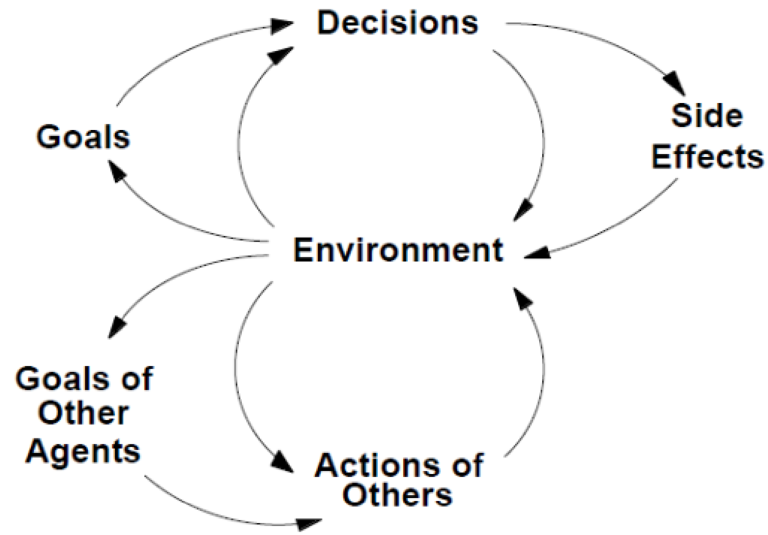
- Constantly changing
- Tightly coupled
- Governed by feedback
- Nonlinear
- History-dependent
- Self-organizing
- Adaptive
- Characterized by trade-offs
- Counterintuitive
- Policy resistant

Open-loop, event-based view of the world





Our decisions alter our environment, leading to new decisions,



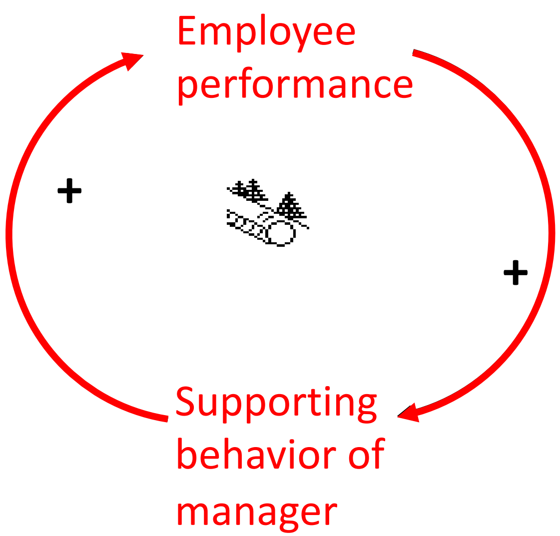
but also triggering side effects, delayed reactions, changes in goals and interventions by others. These feedbacks may lead to unanticipated results and ineffective policies.

Feedback view of the world

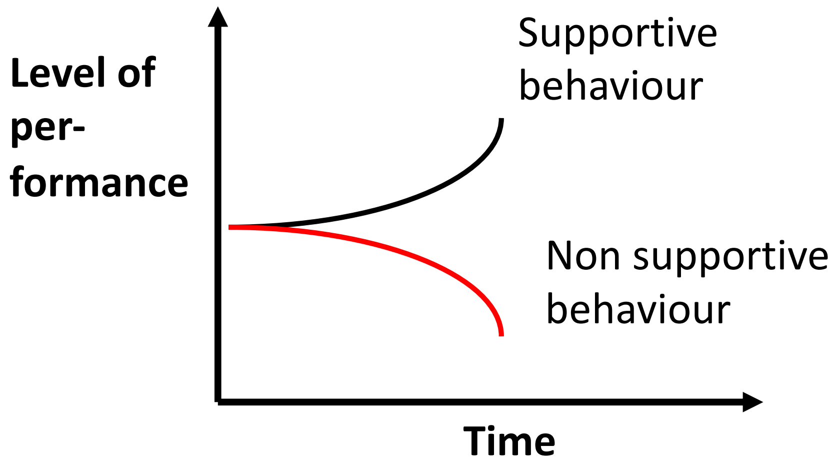
Sterman, 2000

Reinforcing loop

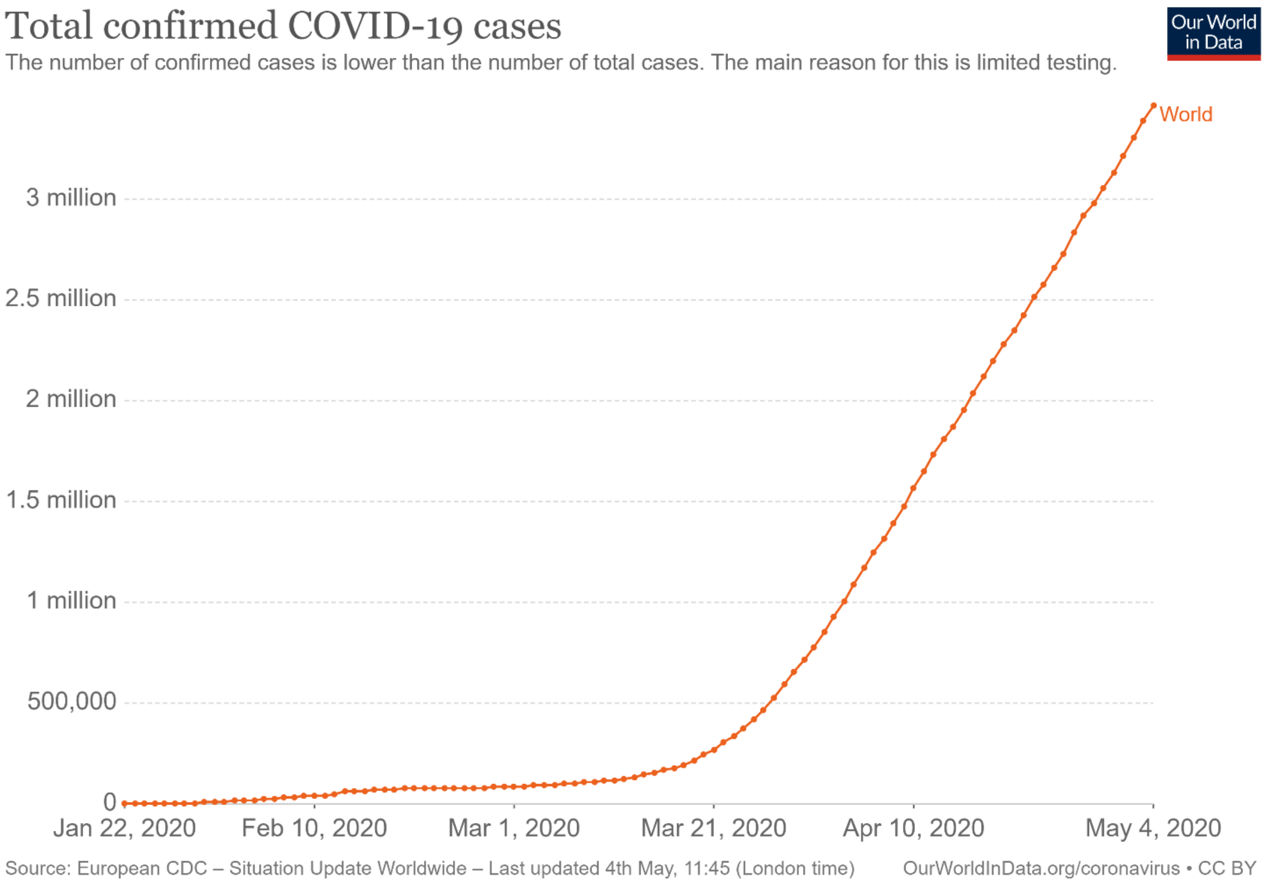
Structure



Behavior in time

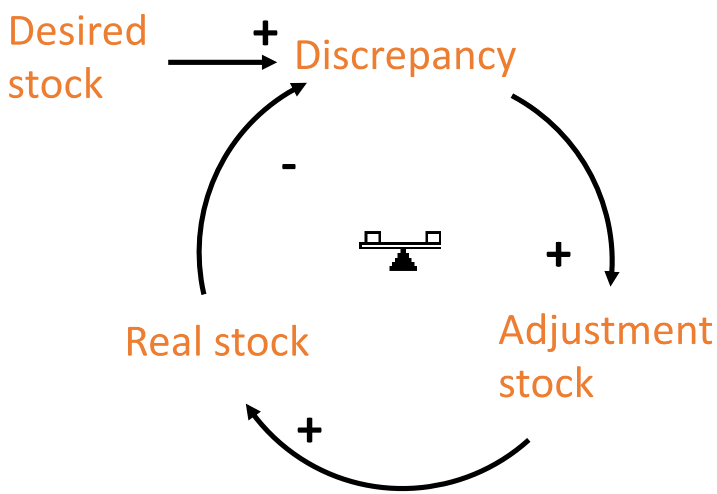


Exponential growth

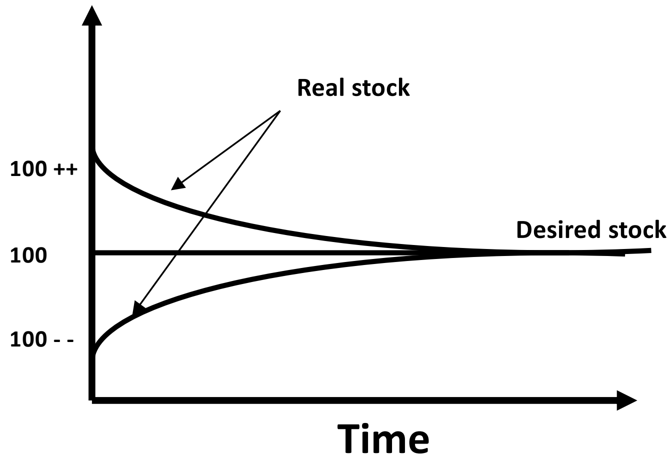


Balancing loop

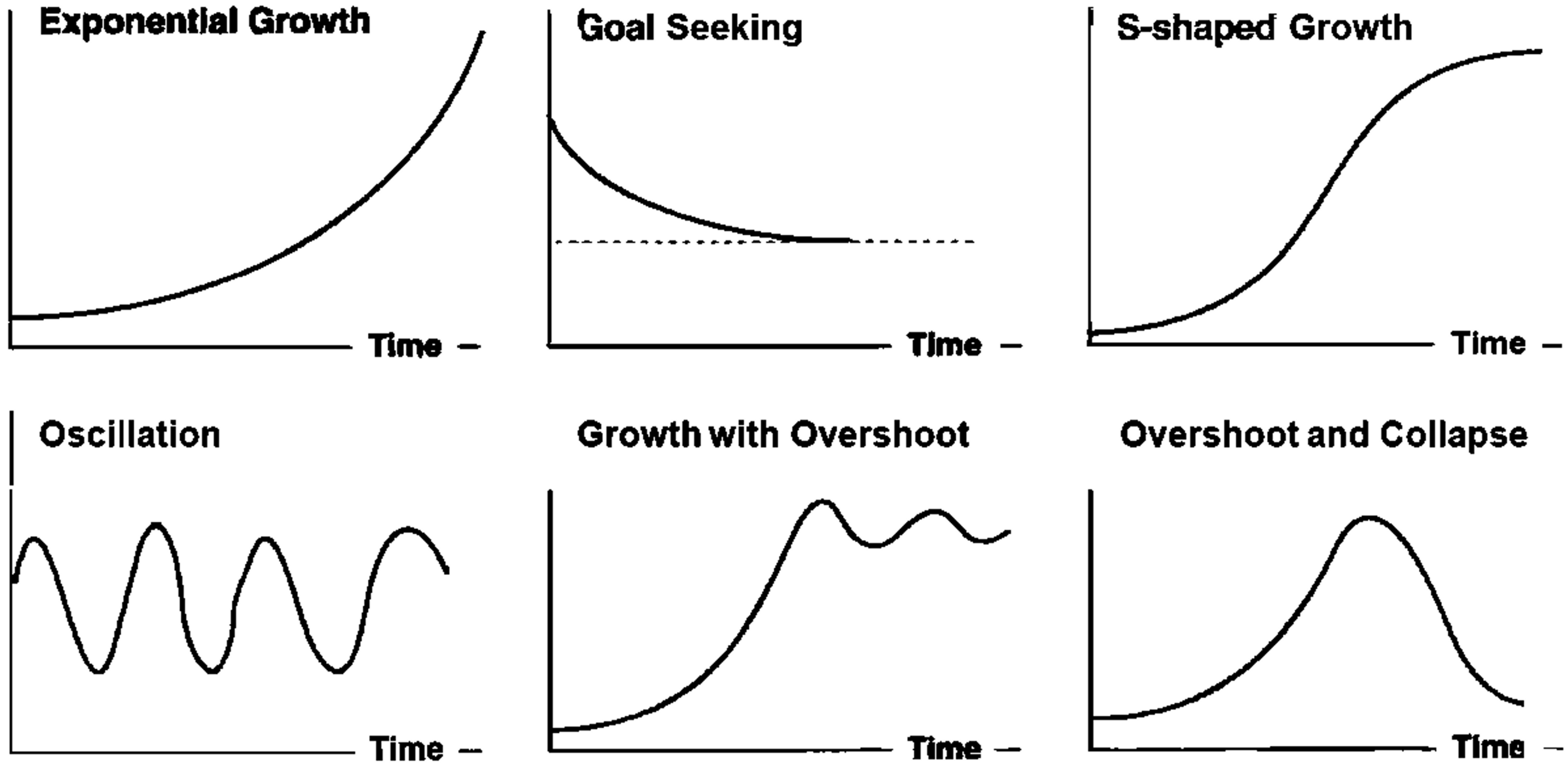
Structure



Behavior in time

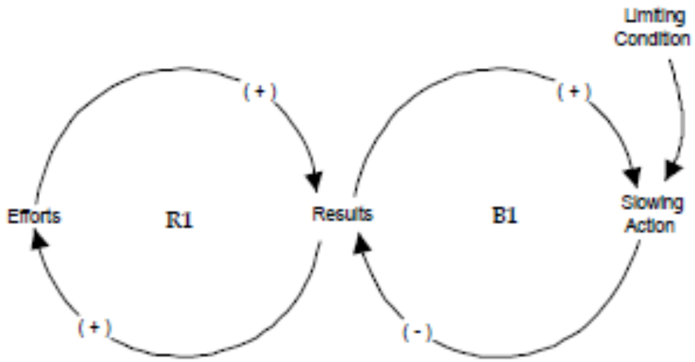


Six common patterns in systems

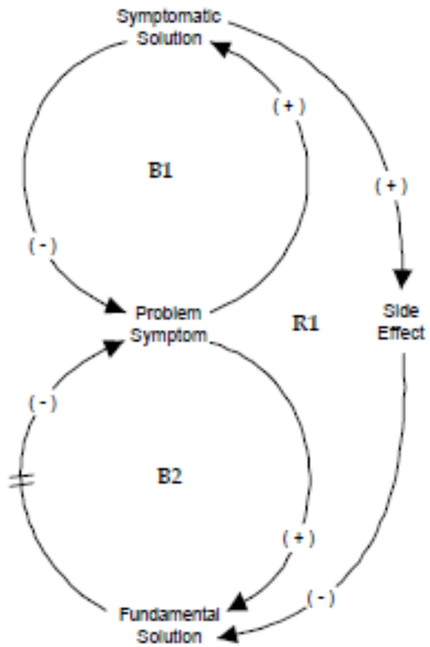


System archetypes

- Limits to growth



- Shifting the burden



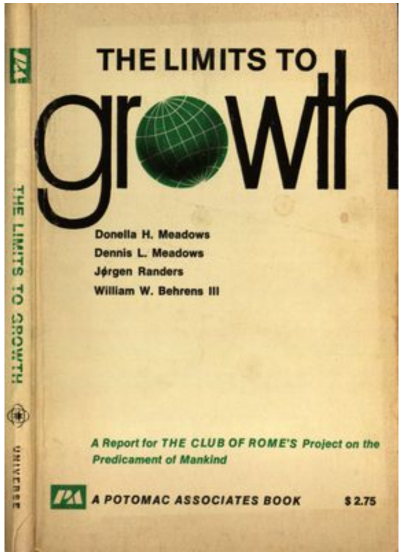
Limits to growth and system dynamics

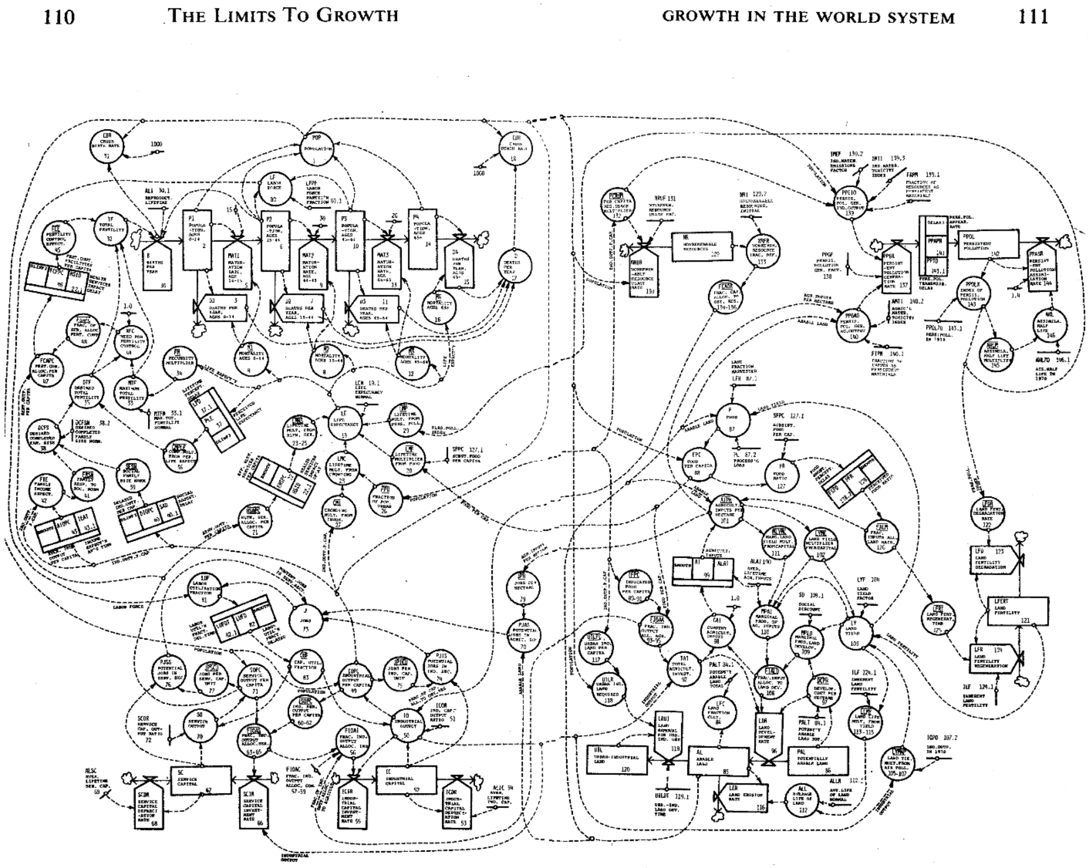
Donella Meadows

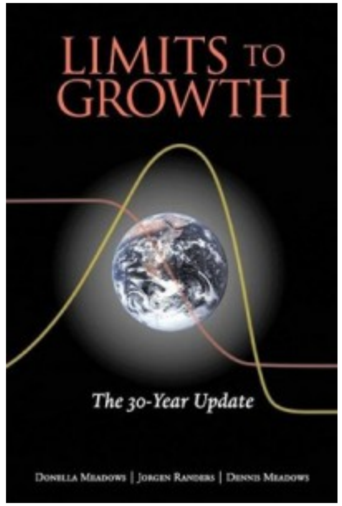
Dennis Meadows

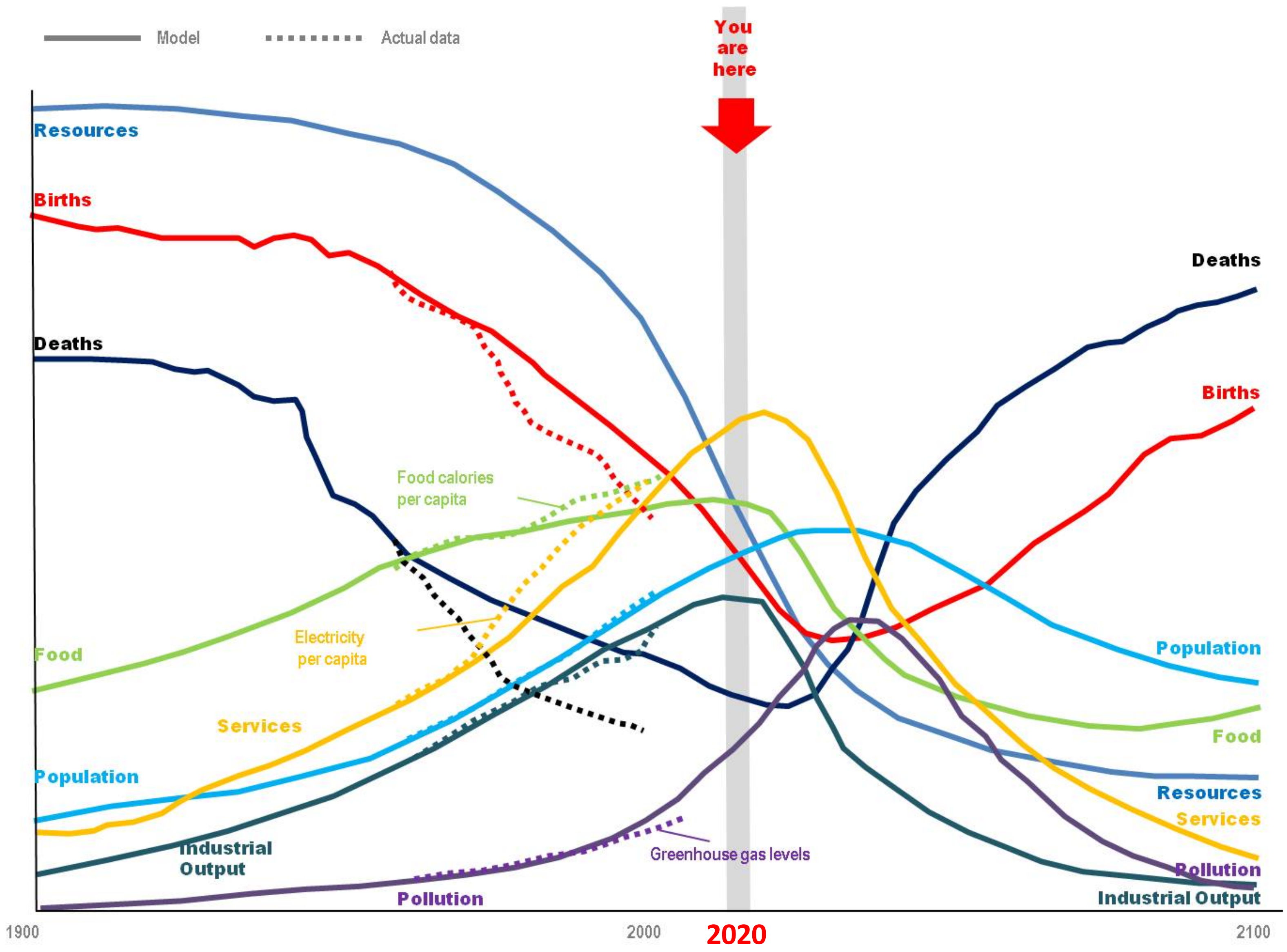
Jørgen Randers

Limits to growth and system dynamics

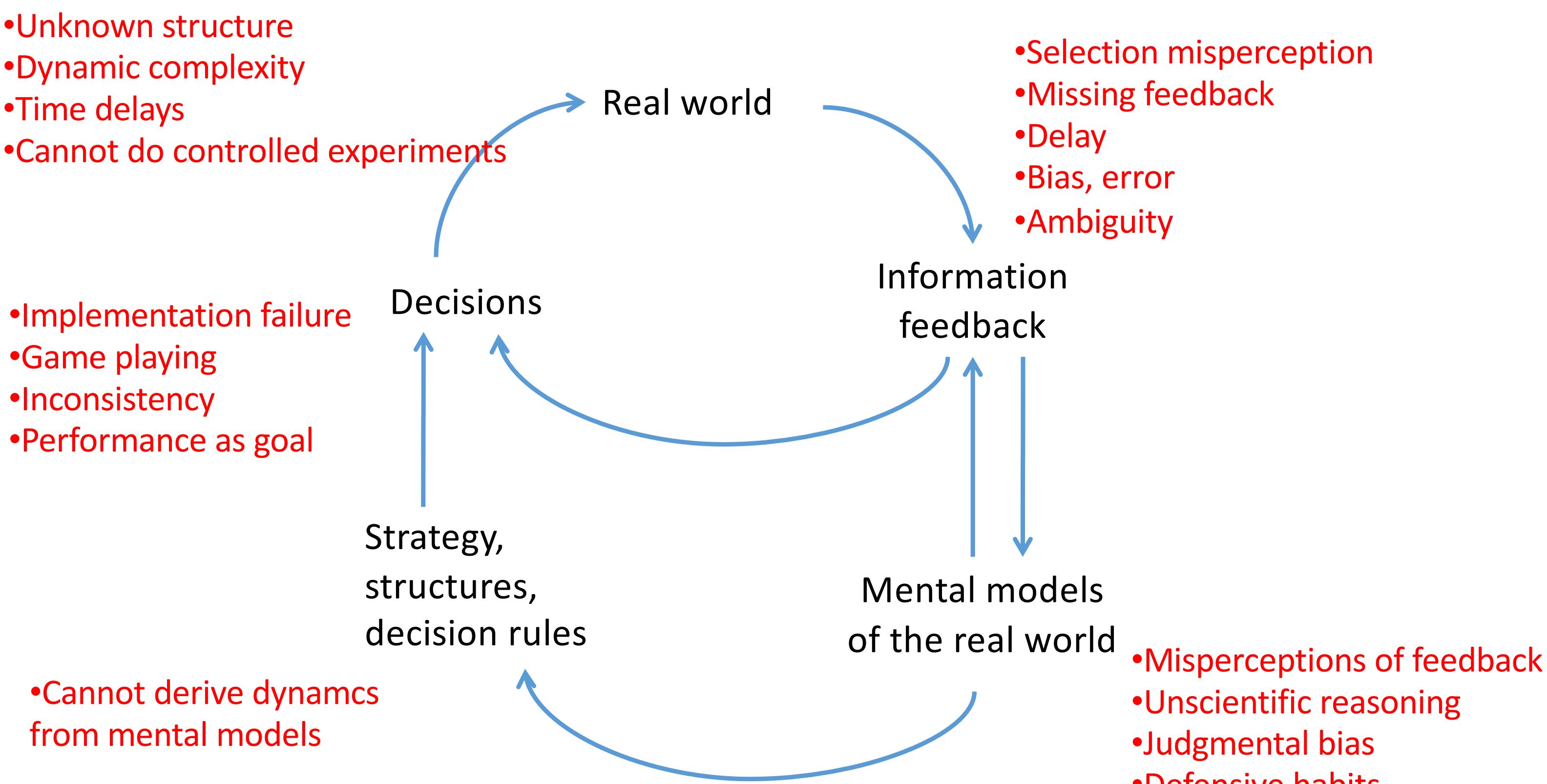







Model
Actual data
You are here
Resources
Births
Deaths
Food calories per capita
Electricity per capita
Food
Services
Population
Industrial Output
Greenhouse gas levels
Pollution
Deaths
Births
Population
Food
Resources
Services
Pollution
Industrial Output
1900
2000
2020
2100

Barriers for learning



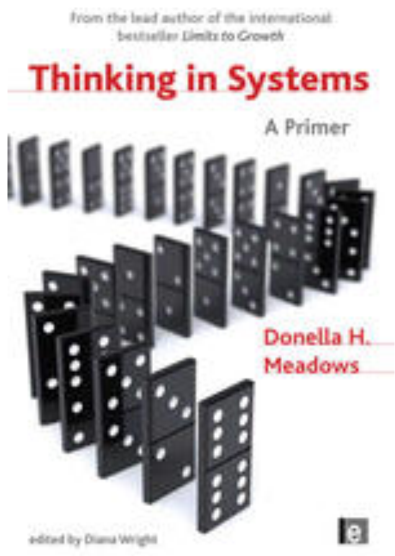
Sterman, 2000

Nature of complexity

- **Dynamic complexity**: cause and effect far apart in space and time, resulting in the need for a **systemic** solution
- **Social complexity**: no single entity owns the problem and stakeholders involved have diverse - potentially entrenched [and antagonistic] - perspectives and interests, resulting in the need for a **participative** solution
- **Generative complexity**: future is unfamiliar and undetermined, resulting in the need for a **creative** solution

12 intervention points

1. Transcending paradigms
2. Paradigms
3. Goals
4. Self-organization
5. Rules
6. Information flows
7. Reinforcing feedback loops
8. Balancing feedback loops
9. Delays
10. Stock-and-flow structures
11. Buffers
12. Numbers



12 intervention points

1. Transcending paradigms
2. Paradigms
3. Goals

→ Purpose based interventions

4. Self-organization
5. Rules
6. Information flows

→ Structure based interventions

7. Reinforcing feedback loops
8. Balancing feedback loops
9. Delays
10. Stock-and-flow structures
11. Buffers
12. Numbers

→ Elements based interventions

Source: Meadows (2009)

How to intervene in complex systems?

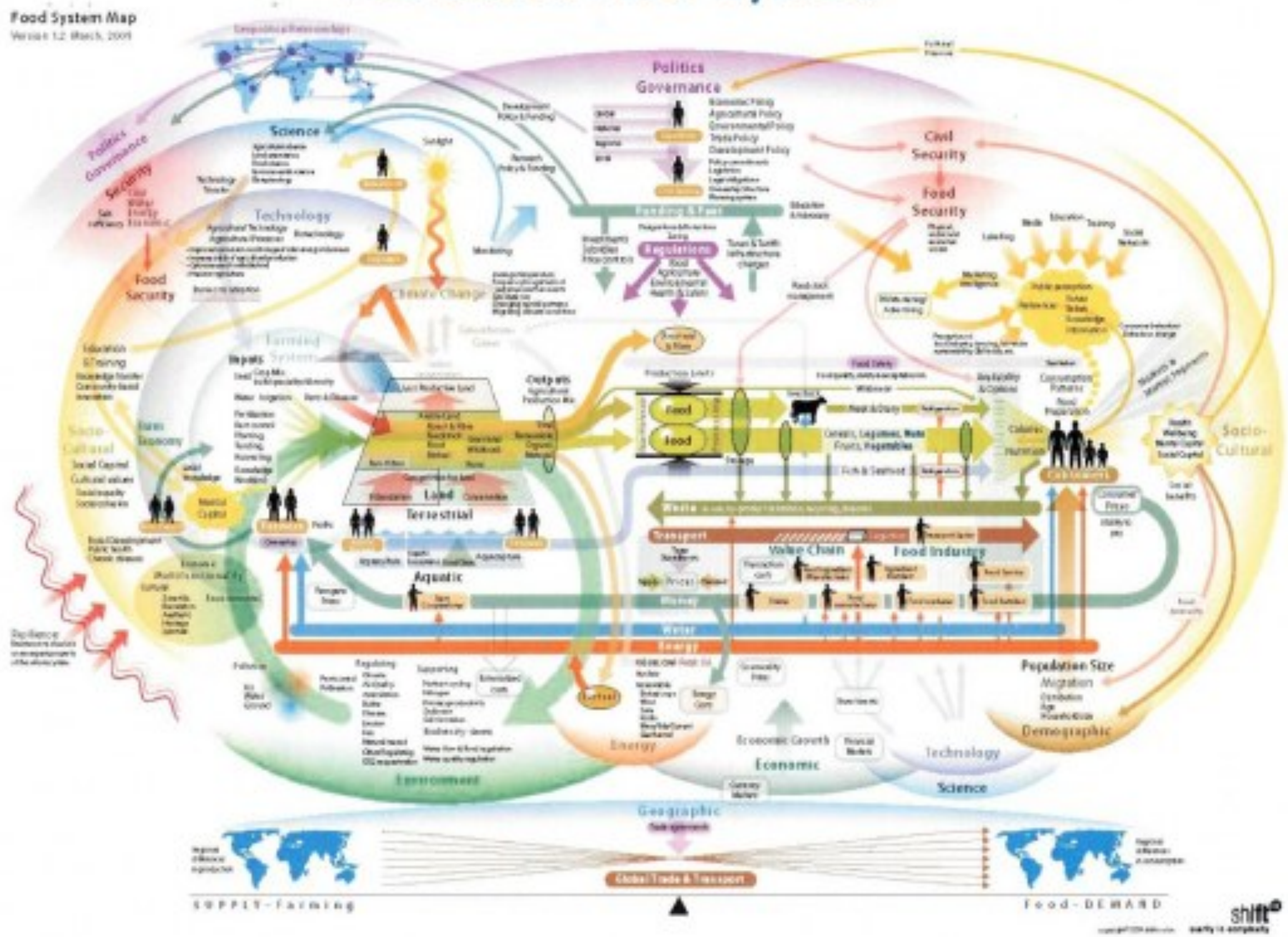
	Relationship between cause and effect	Approach	Respons
Simple	Obvious	Sense - Categorise - Respond	Best practice
Complicated	Requires analysis and expert knowledge	Sense - Analyze - Respond	Good practice
Complex	Only in retrospect	Probe - Sense - Respond	Emergent practice
Chaotic	Not at systems level	Act - Sense - Respond	Novel practice
Disorder	?	?	Comfort zone

Source: Cynefin

Part 3

Food systems as complex systems

The Global Food System

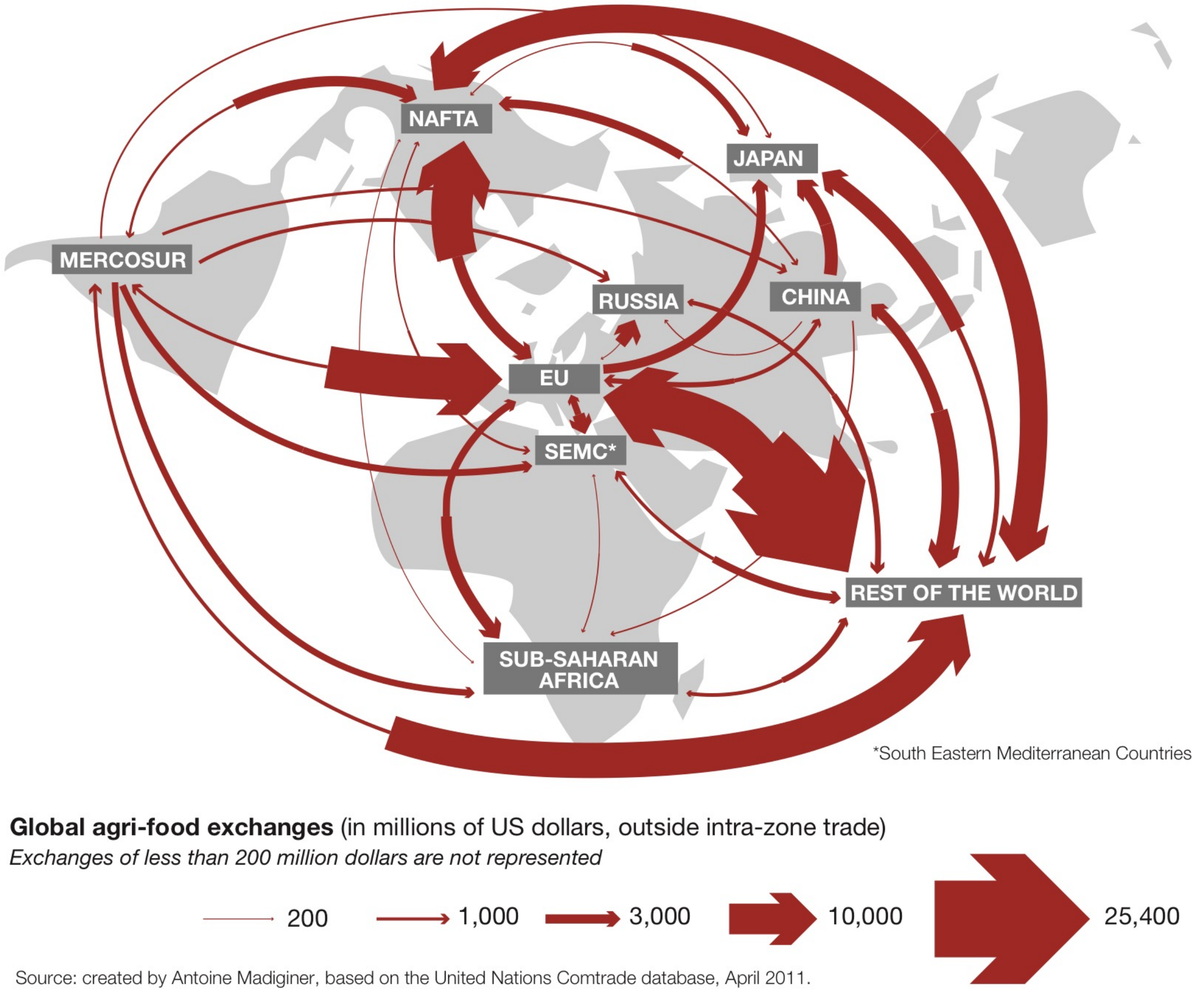


Source: shiftn

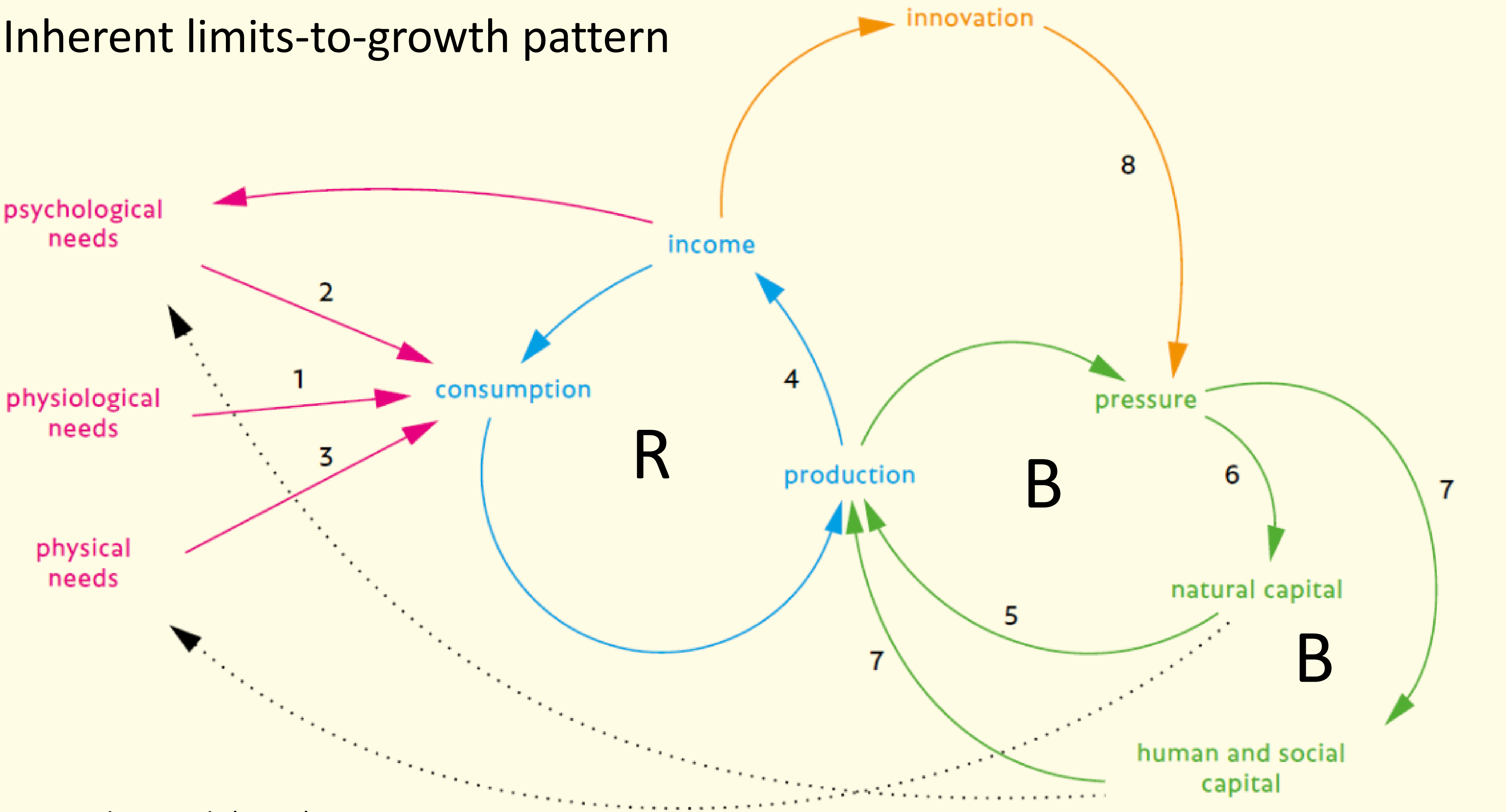
Some food system dynamics

- Dynamic complexity:
  - Cause and effect far apart in space and time
  - Inherent limits-to-growth pattern in the food system
  - ‘Memories’ create path dependencies and lock-ins
- Social complexity:
  - Stakeholders involved have diverse - potentially entrenched [and antagonistic] - perspectives and interests
- Generative complexity
  - Future is unfamiliar and undetermined

Cause and effect far apart in space and time



Inherent limits-to-growth pattern



Mathijs et al. (2012)

BBB as knowledge and action lock-in

GeoJournal (2008) 73:31–44
DOI 10.1007/s10708-008-9176-2

Steak up to the horns!

The conventionalization of organic stock farming: knowledge lock-in in the agrifood chain

Pierre M. Stassart · Daniel Jamar

The “What is a good farmer?” lock-in

Lock-Ins Acting against Changes in Pathways of Change by Farmers
Mainstream dairy cooperatives offer bonuses as from a certain quantity of milk and are reluctant to collect milk from small-scale farms
Dairy farmers share a common vision about farming practice based on intensification, and the education of farmers contribute to this common vision
Public agricultural advisers and banks support farming practices based on intensification, growth and high investment
Dairy farmers define themselves as milk producers
The high workload on farms and the heavy investments in farm equipment hinder changes in milk processing practices
Mainstream dairy cooperatives offer a sense of security

De Herde, V.; Maréchal, K.; Baret, P.V. Lock-ins and Agency: Towards an Embedded Approach of Individual Pathways in the Walloon Dairy Sector. *Sustainability* **2019**, *11*, 4405.

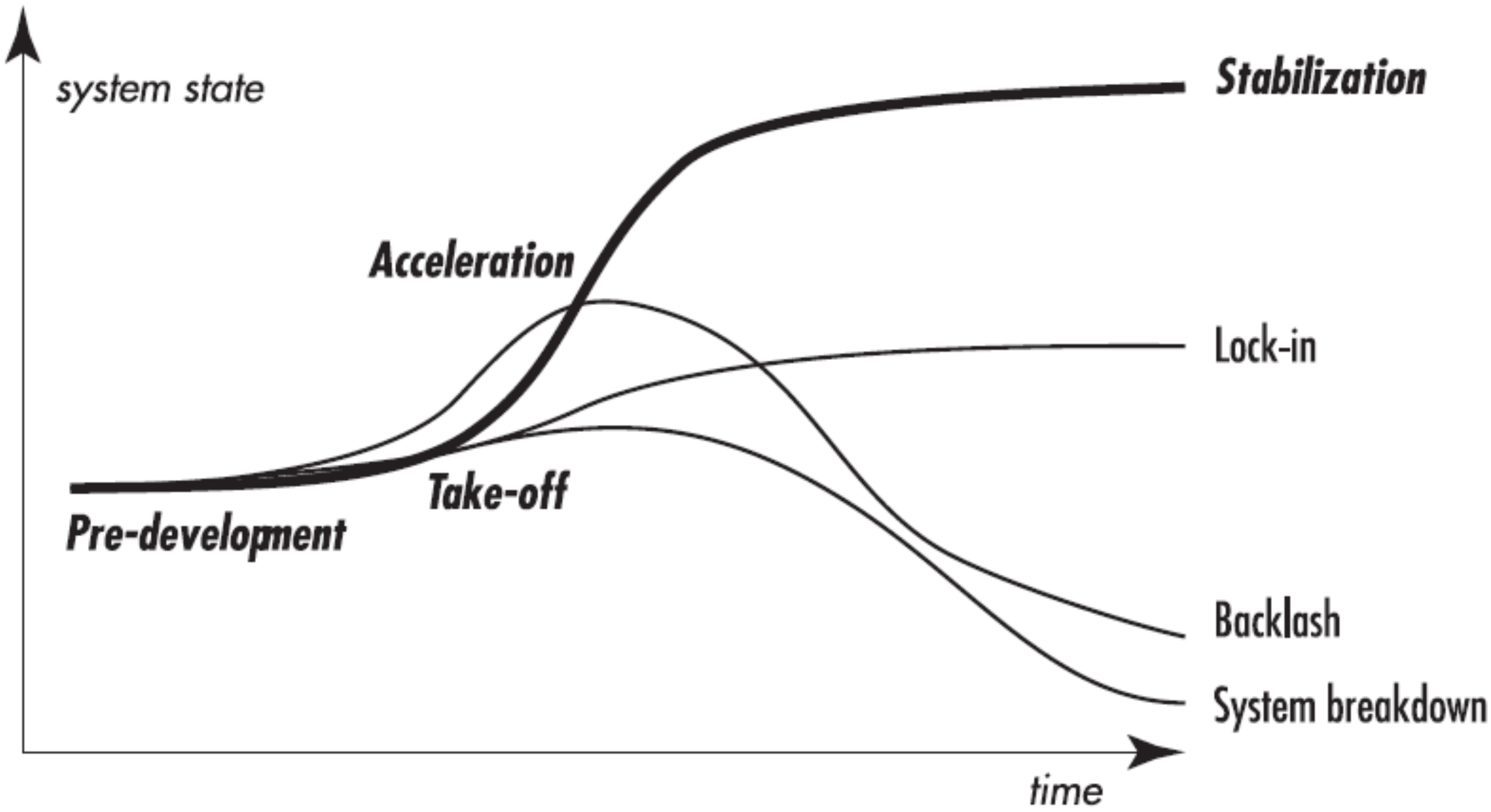
Stakeholders involved have diverse - potentially entrenched [and antagonistic] - perspectives and interests

- Agro-ecological farming versus “industrial” agriculture
- Family versus corporate
- GMO, crispr-cas
- Land sparing versus land sharing
- Animal versus plant
- Global versus local
- Large versus small
- …

https://publicwiki.deltares.nl/display/KWI/5.2.1.3.+Zilte+landbouw+in+Zeeland

Future is unfamiliar and undetermined

https://time.com/collection/best-inventions-2019/5733085/aerofarms/


system state
Stabilization
Acceleration
Lock-in
Take-off
Pre-development
Backlash
System breakdown
time

Concluding remarks

- Food system is a complex system facing formidable challenges
- Technological solutions are known
- Social complexity inhibits implementation, as change is inhibited by vested interests
- Learning by doing: Probe – sense – respond as action logic (in addition to sense – analyse – respond)

References

- Freibauer, A. et al., 2011. Sustainable Food Consumption and Production in a Resource-constrained World. Summary Findings of the EU SCAR Third Foresight. Eurochoices, 10 (2), 38-43.
- Jackson, P. et al., 2020. A sustainable food system for the European Union. A sustainable food system for the European Union, 1-224, doi: 10.26356/sustainablefood
- Mathijs, E. et al., 2012. Transition to a sustainable agro-food system in Flanders: a system analysis. MIRA Topic Report in collaboration with AMS, Department of Agriculture and Fisheries.
- Meadows, D.H., 2009, Thinking in Systems: A Primer, Earthscan.
- Perman, R. et al., 2003, Natural Resource and Environmental Economics, Third Edition, Pearson.
- Sterman, J.D., 2000. Business Dynamics: Systems Thinking and Modellilng for a Complex Word, McGraw-Hill.