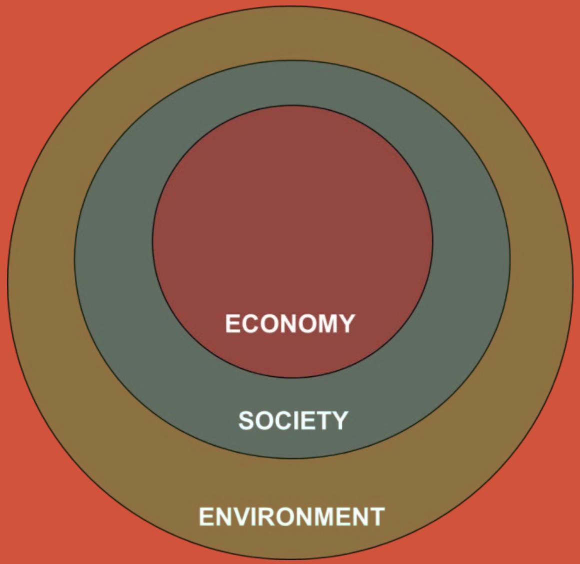
# A sustainable world

## Quantifying the engineering challenge

**Bill Grace**

September 2012




# Sustainability – sorting out the concept

# Brundtland

*'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'*

Source: Our Common Future

# Brundtland

*'development that meets the **needs** of the present without compromising the ability of **future generations** to meet their own needs'*

***Enduring human wellbeing***

# Systems thinking

# Sustainability as a *'place-based'* concept

- Interconnection between places
- Dependencies
  - between people, and
  - between people and the bio-physical environment, and
  - within the bio-physical environment
- Circular causation - feedback

*"Complex systems are composed of a large number of active elements whose rich patterns of interactions produce emergent properties that are not easy to predict by analysing the separate parts of the system."*

Source: Ostrim 1999

# Sustainability as a *'place-based'* concept

*Places are complex, dynamic, non-linear socio-ecological systems*

# Sustainability & resilience

**Resilience**

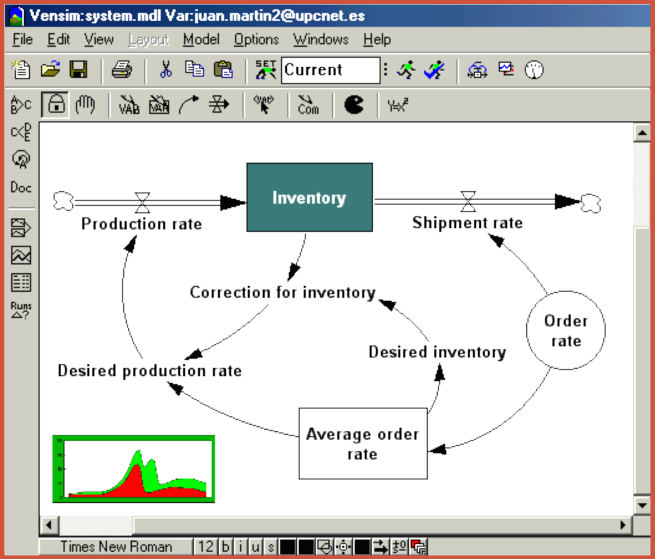
*"The capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks"*

- Resilience is about dynamic stability
- Necessary but insufficient for sustainability

Sustainability Goal

*Healthy & Resilient Socio-ecological Systems*

Source: Resilience Alliance




# System dynamics

# Invented by an engineer

Jay W. Forrester
Professor Emeritus, MIT

# The simulation of dynamic systems

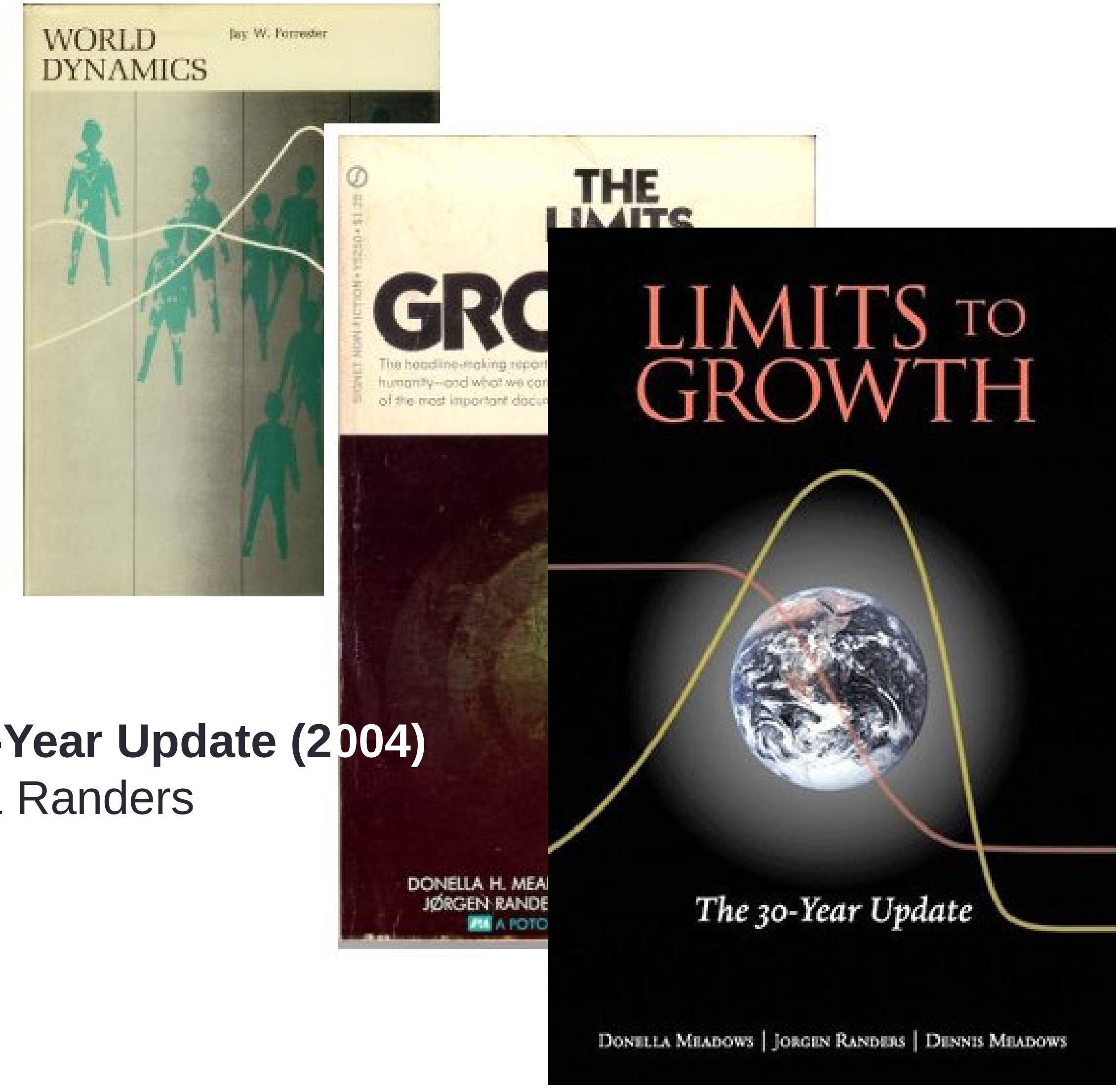
**Urban Dynamics** (1969)
JW Forrester

**World Dynamics** (1971)
JW Forrester

**Limits to Growth** (1972)
Meadows, Meadows,
Randers & Behrens

**Beyond the Limits** (1992)
Meadows, Meadows
& Randers

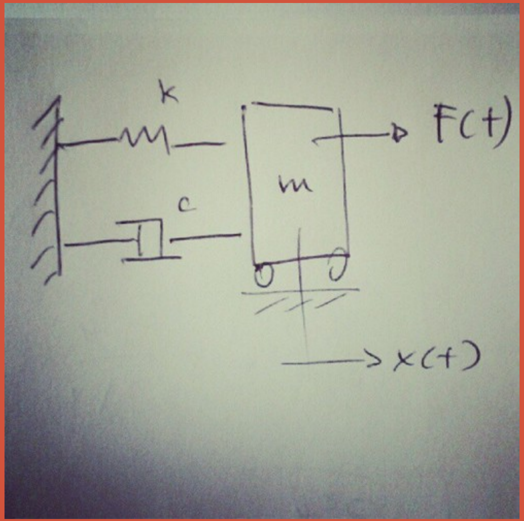
**Limits to Growth: The 30-Year Update (2004)**
Meadows, Meadows & Randers



# The problem with models!

The system dynamics mantra:

*‘All models are  wrong – some are useful’*




# A simple global sustainability model

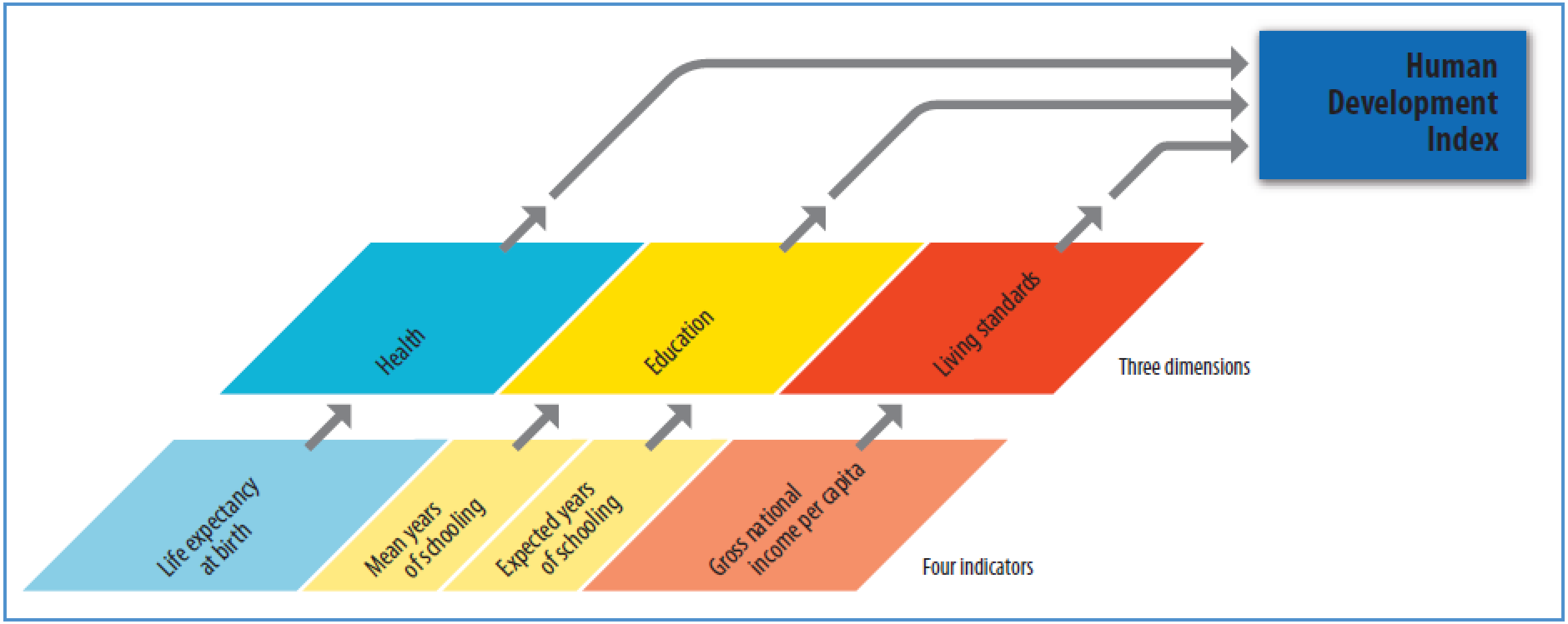
# The dynamics of Human Wellbeing

Living
Standards

# Human Development Index

**Components of the Human Development Index**

The HDI—three dimensions and four indicators

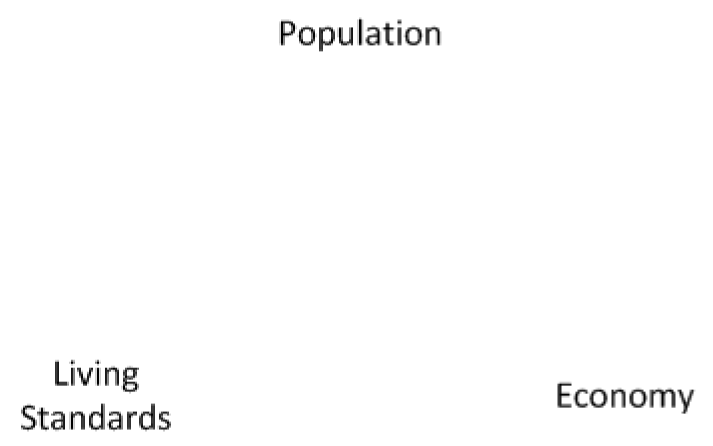



*Note:* The indicators presented in this figure follow the new methodology, as defined in box 1.2.

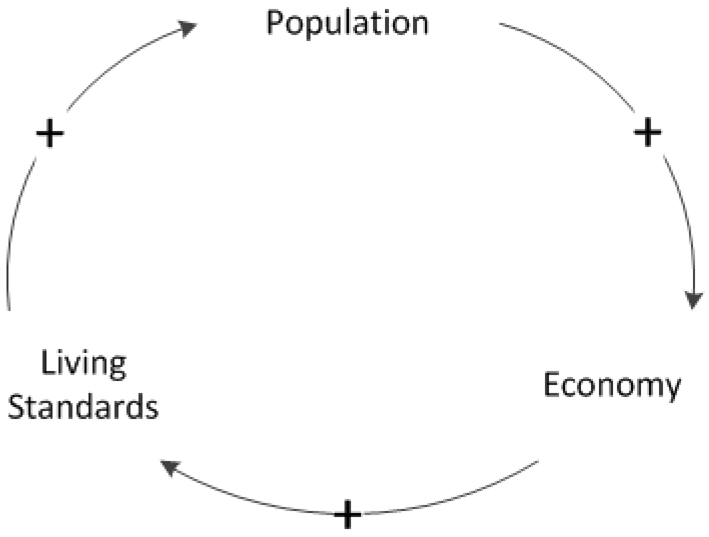
*Source:* HDRO.

Source: UNDP

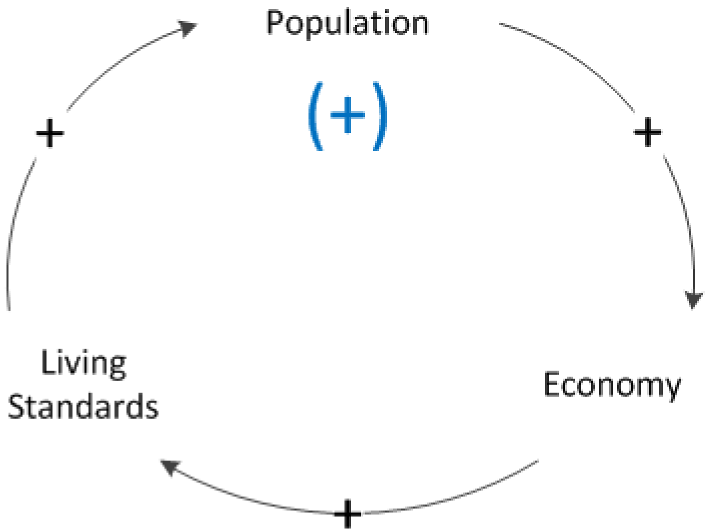
# Key historical dependencies ….



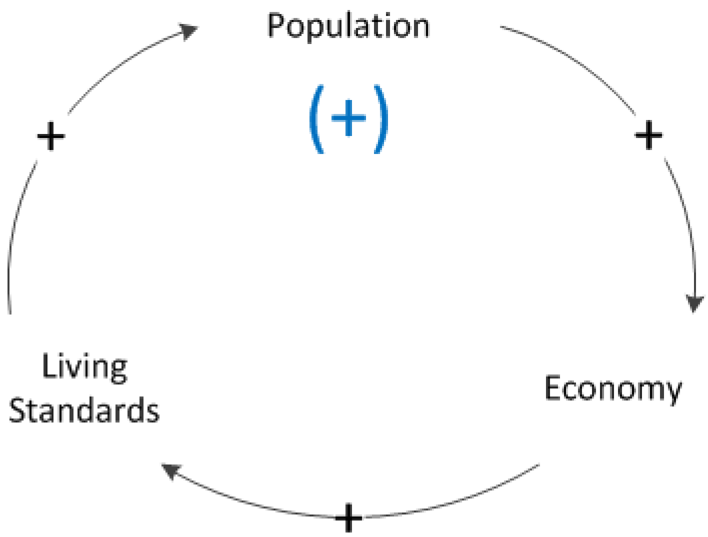
# Circular causation .....

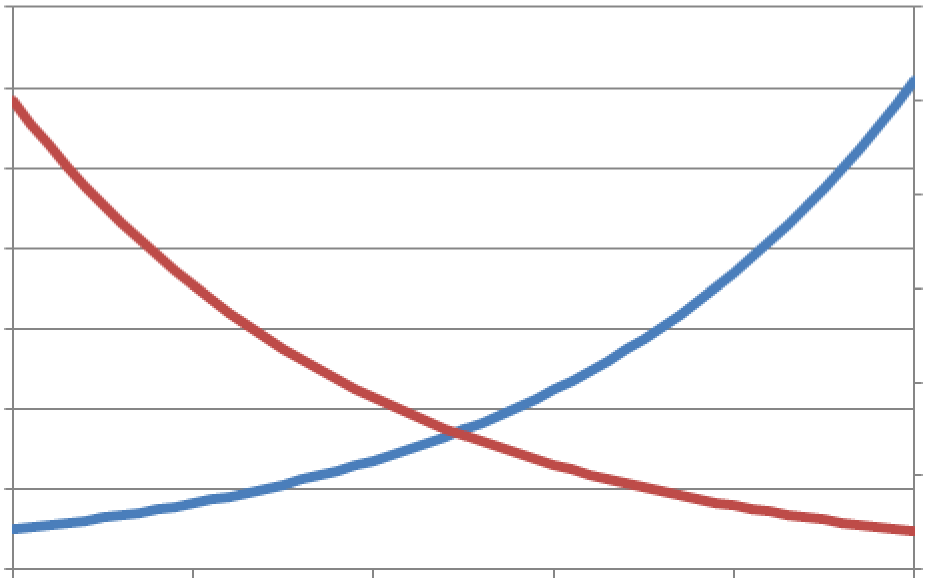


# A reinforcing loop



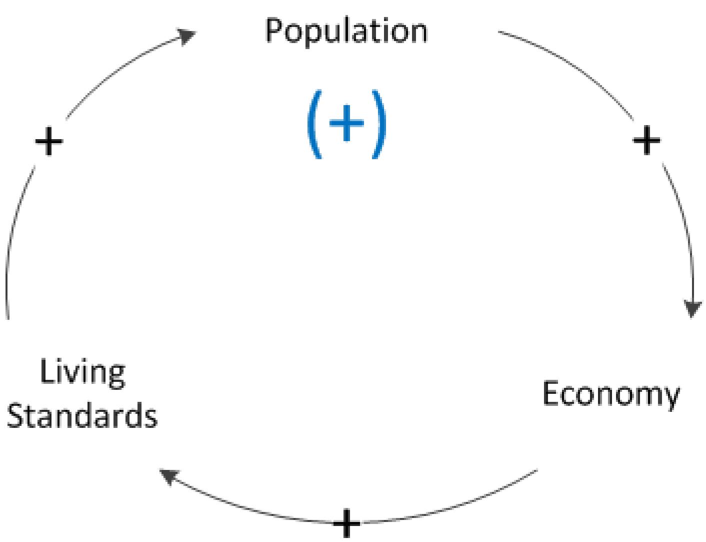
# Reinforcing loops - exponential growth / decline

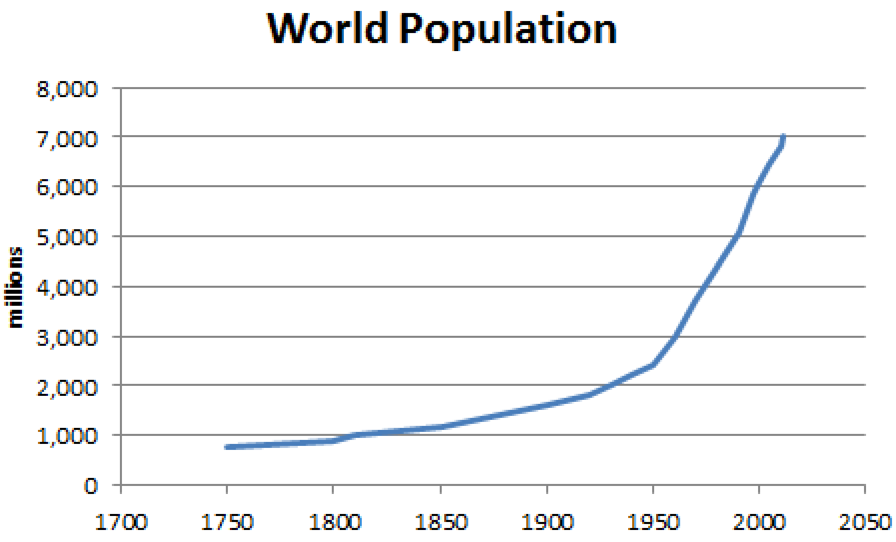


- Virtuous / viscous cycle
- Compound interest
- Escalation
- Market growth

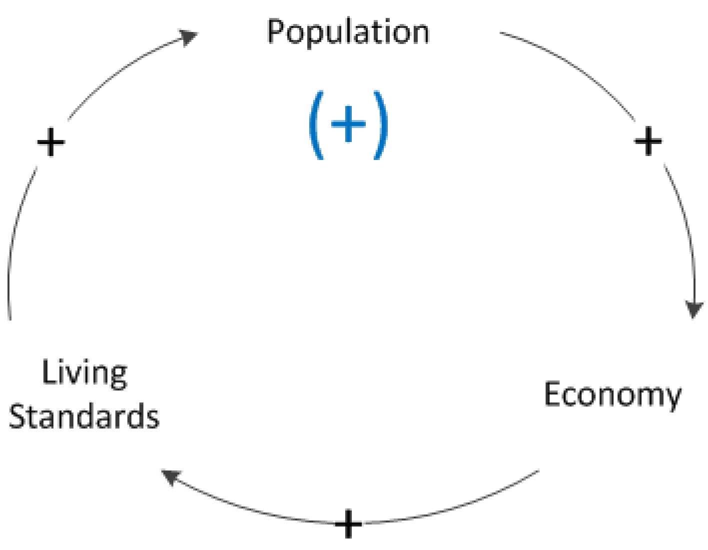
# Exponential growth - population

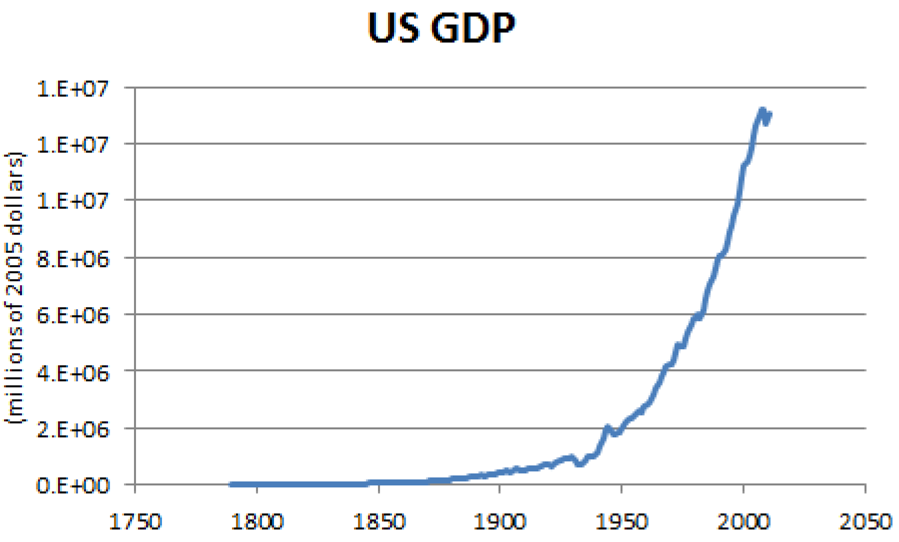



Source: US Dept Commerce / UN

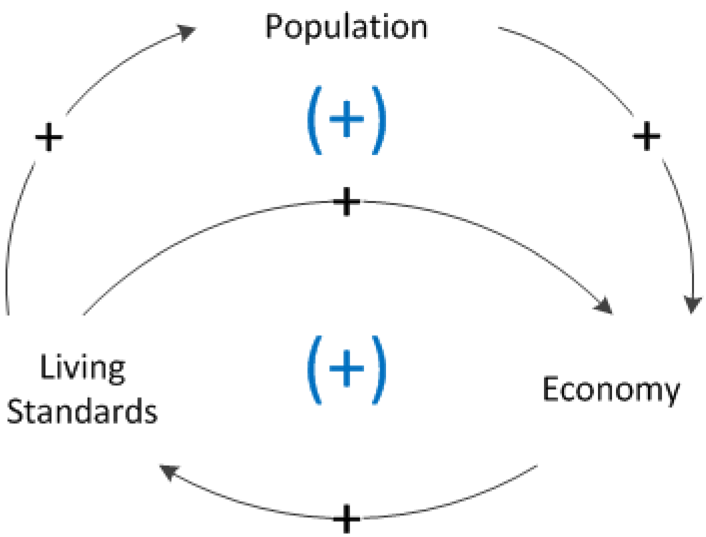
# Exponential growth - economy

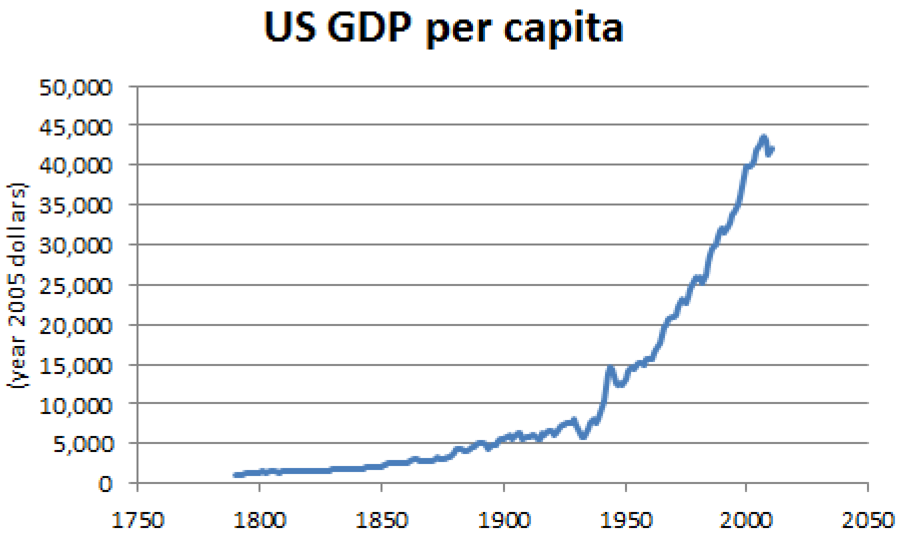



Source: Measuring Worth, 2011.

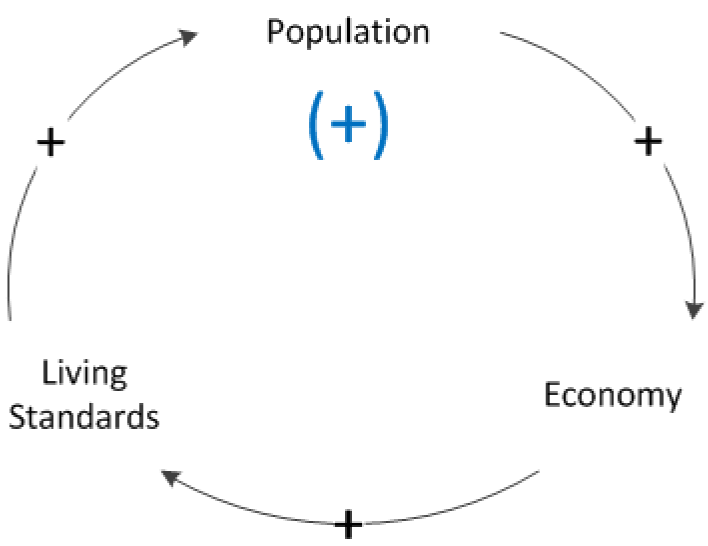
# The Economy – growth on growth!

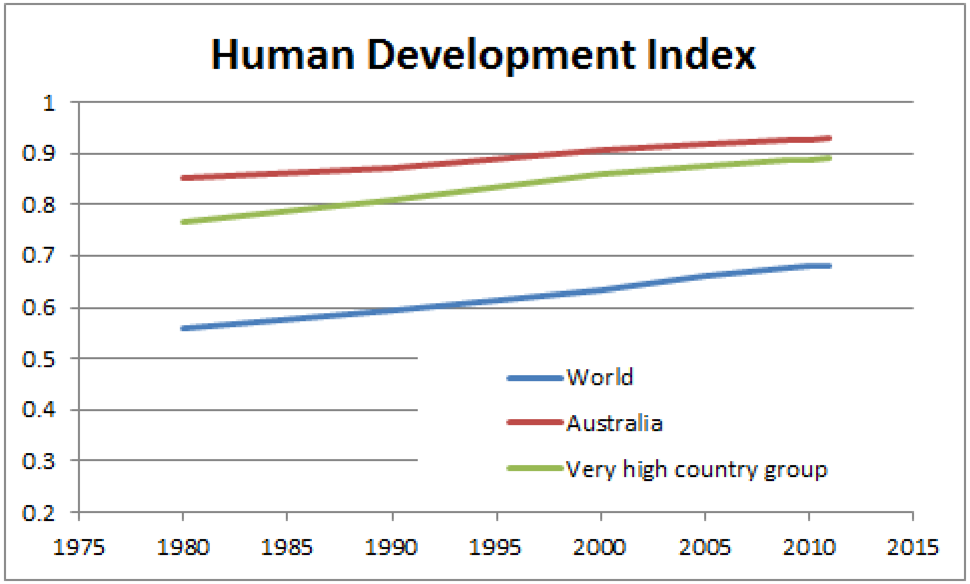



Source: Measuring Worth, 2011.

# Reinforcing loops - exponential growth

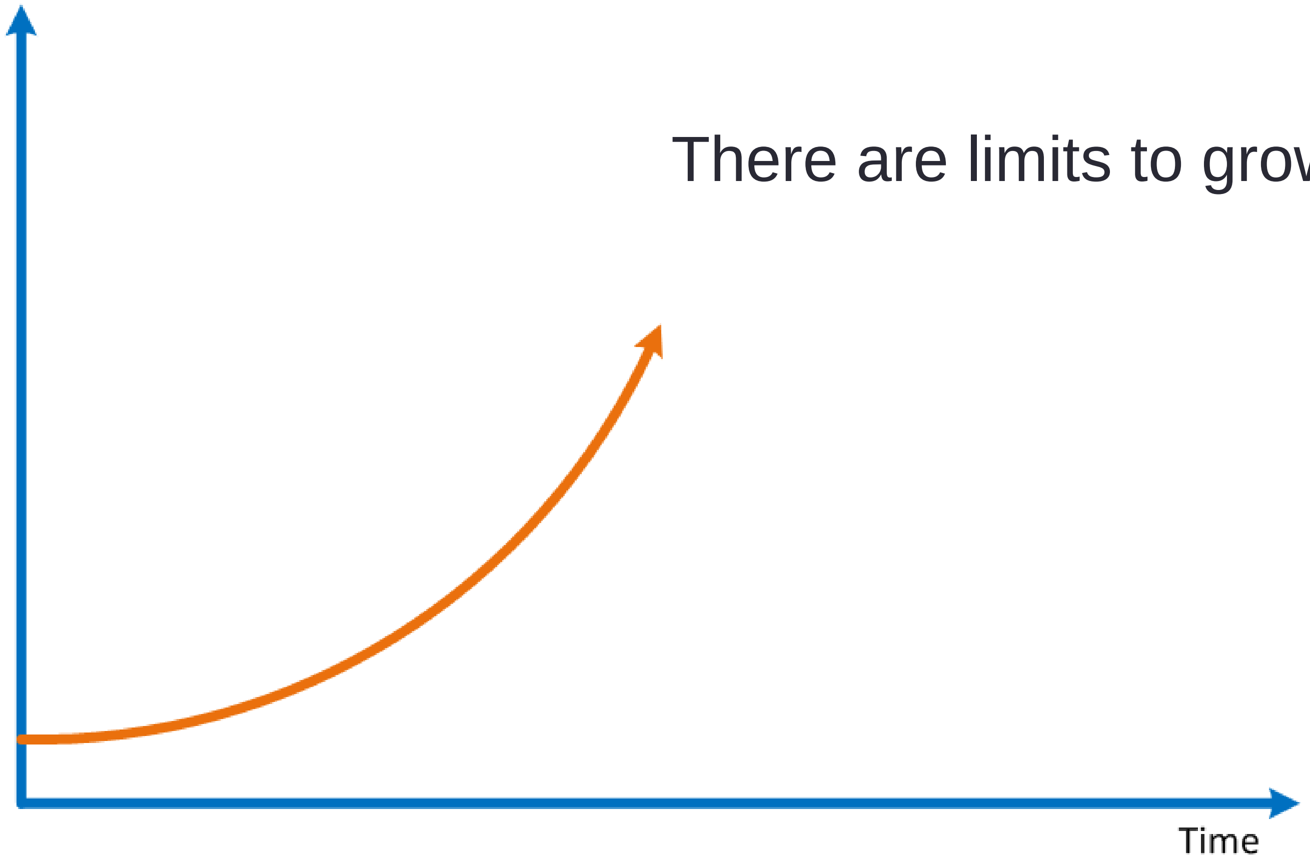


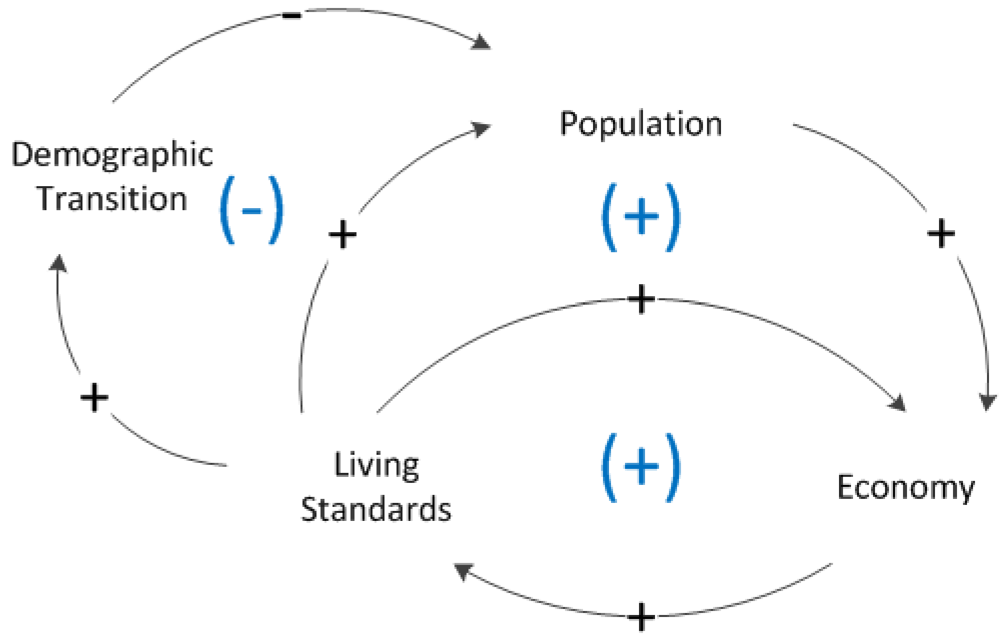

Source: UNDP

# Exponential growth doesn't last forever

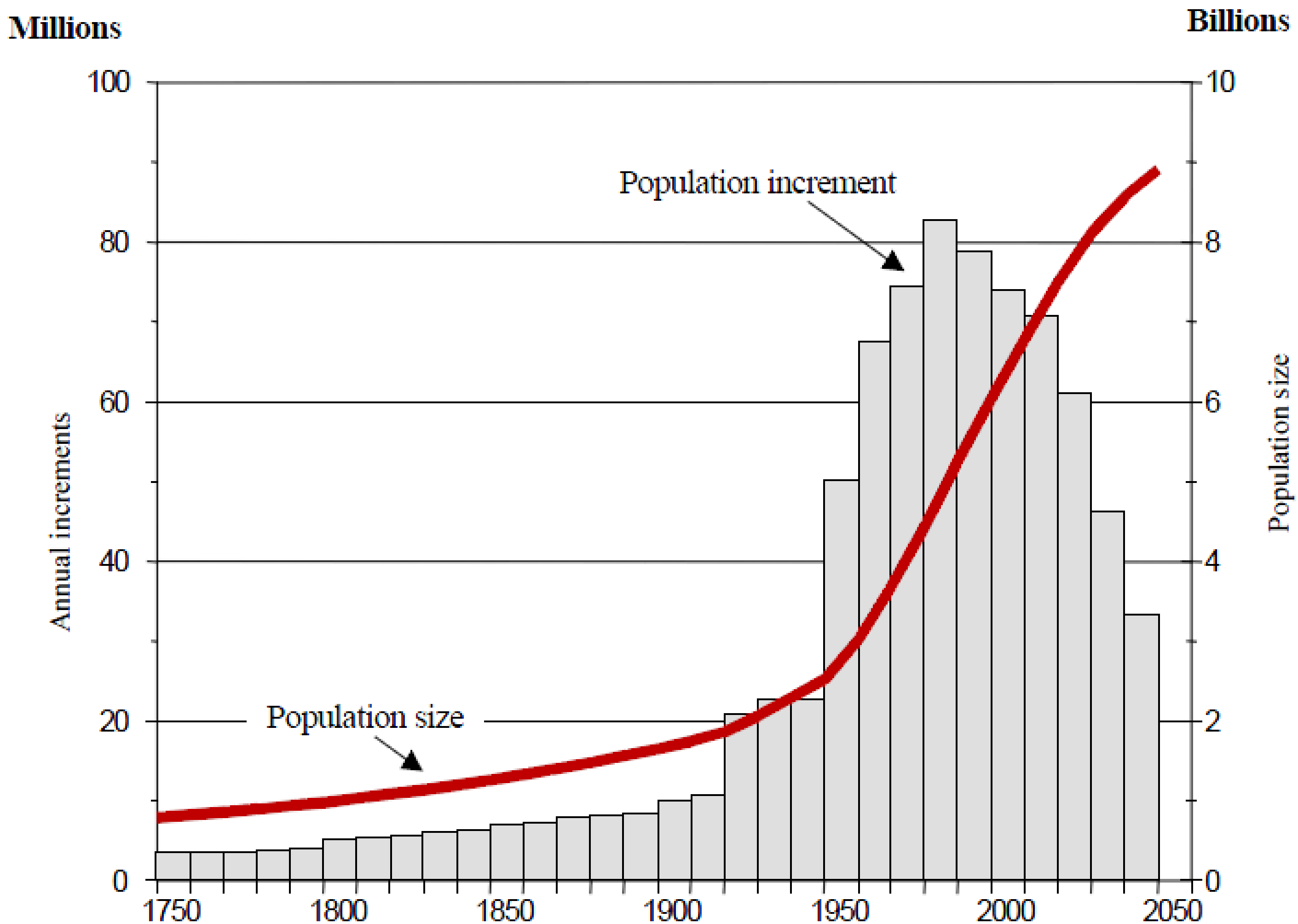
There are limits to growth!



# Balancing loops – counteract growth

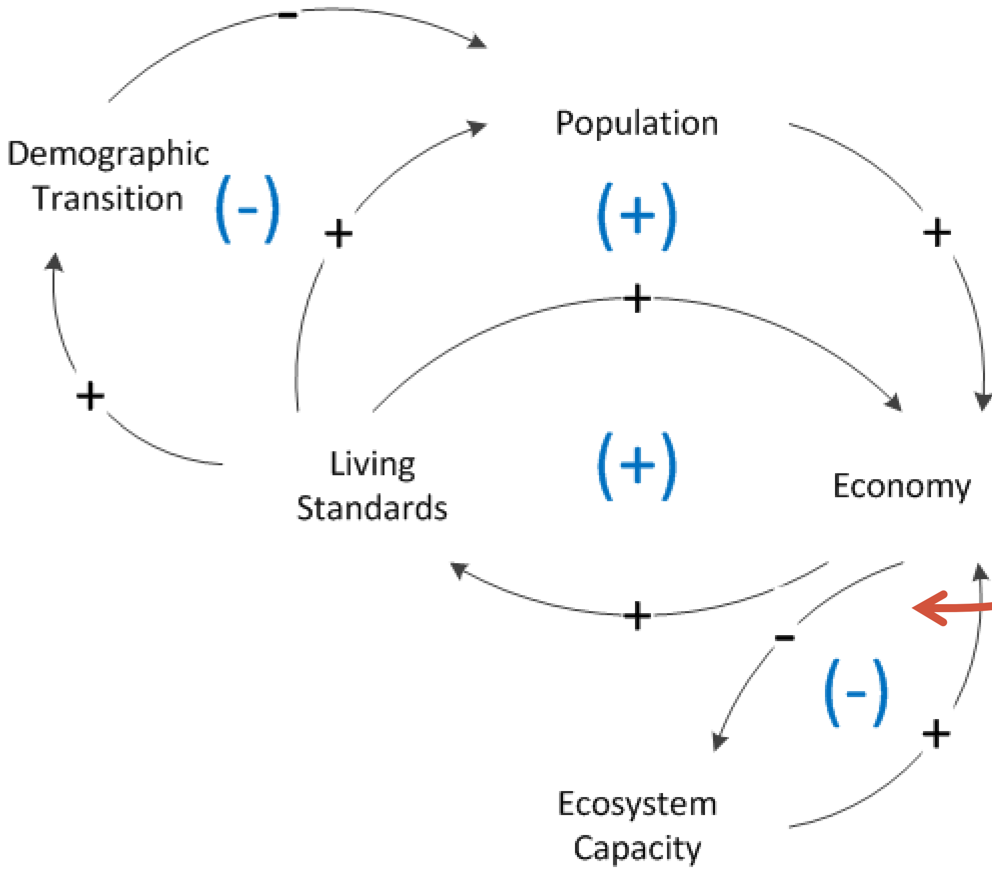


# Global population growth is slowing



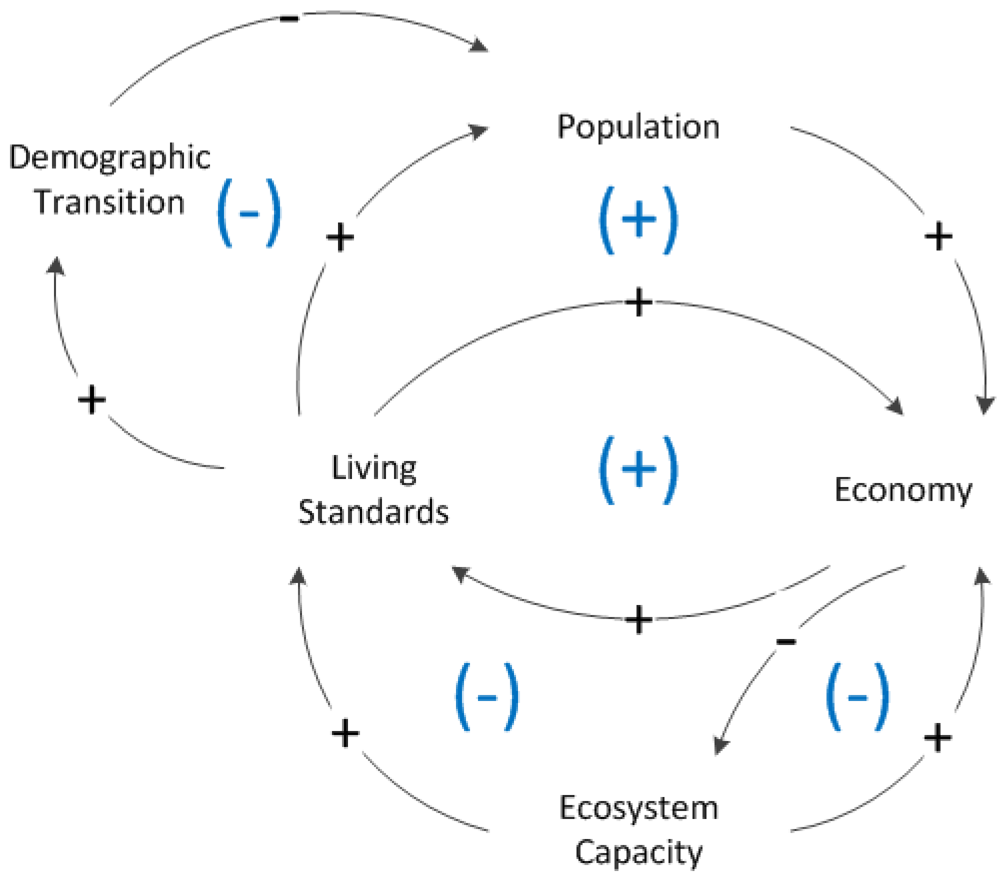

Source: UN Population Division

# And the other balancing loops …




More accurately, the energy and material throughput of the economy

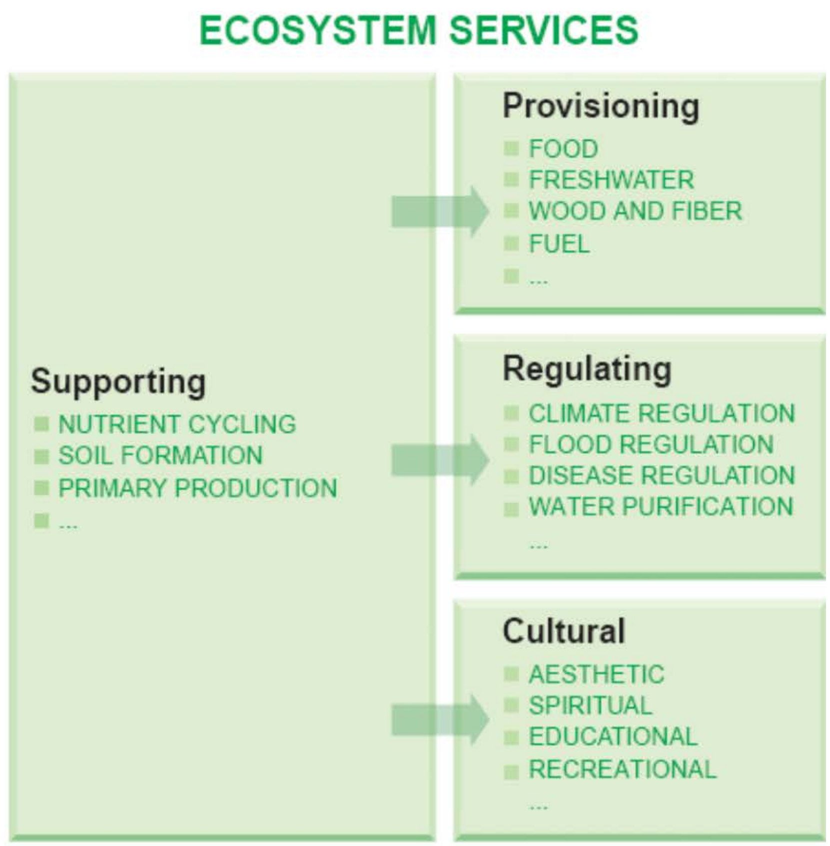
# Two other important balancing loops



# Focus: Ecosystem Services

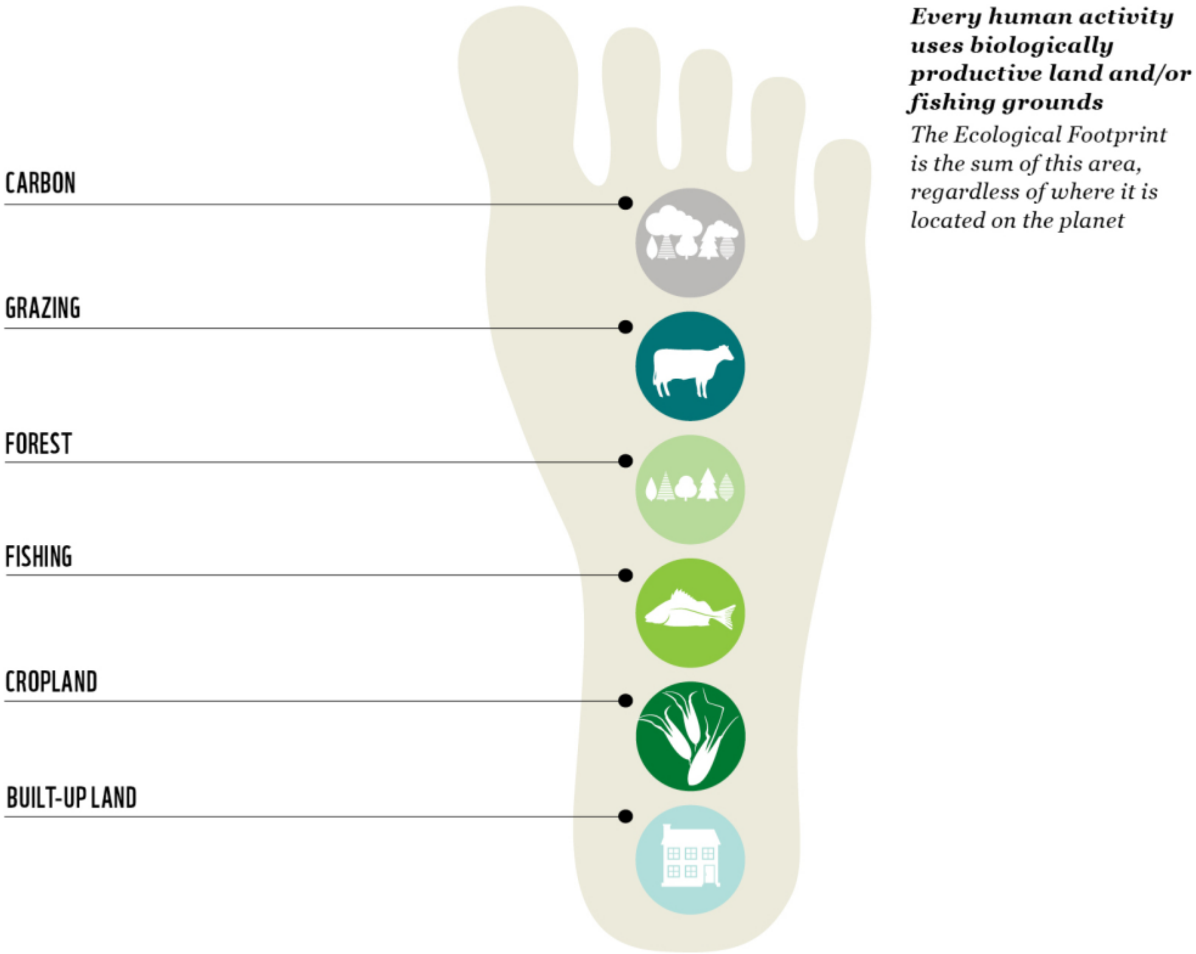
## The benefits people obtain from ecosystems

Millennium Ecosystem Assessment




Source: Millennium Ecosystem Assessment

# The ecological footprint




Source: WWF Living Planet Report 2010

# The ecological footprint calculation

**Ecological Footprint** represents demand for renewable resources

**Biocapacity** represents the availability of resources

**EF ratio = Ecological Footprint / Biocapacity**

expressed in units called global hectares (gha)

1gha representing the productive capacity of 1ha of land at world average productivity

Source: WWF Living Planet Report 2010

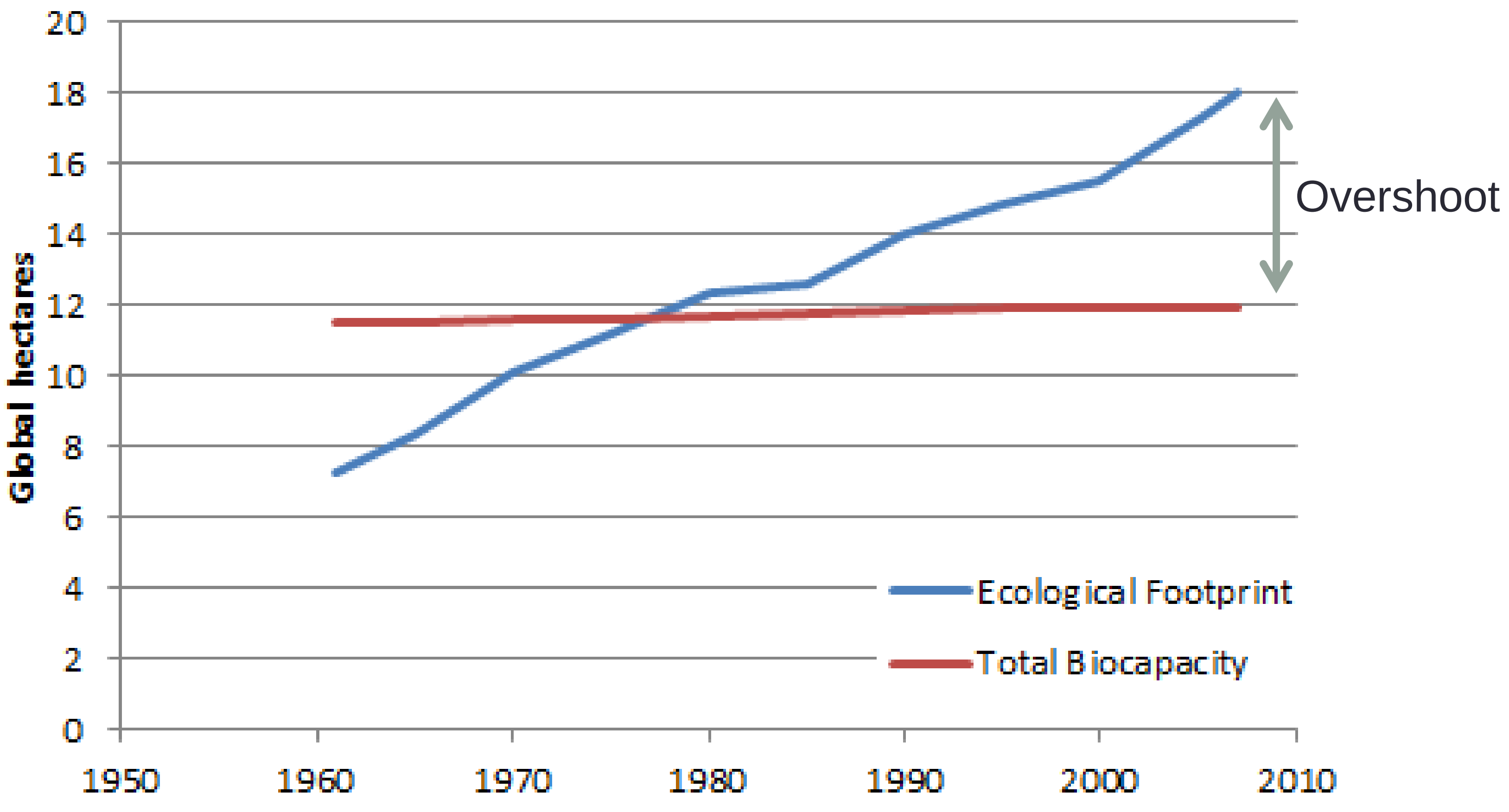
# The ecological footprint calculation

Does not include:

- Waste and pollution (except carbon)
- Non-renewable resources – minerals and fossil fuels
- Loss of regeneration capacity

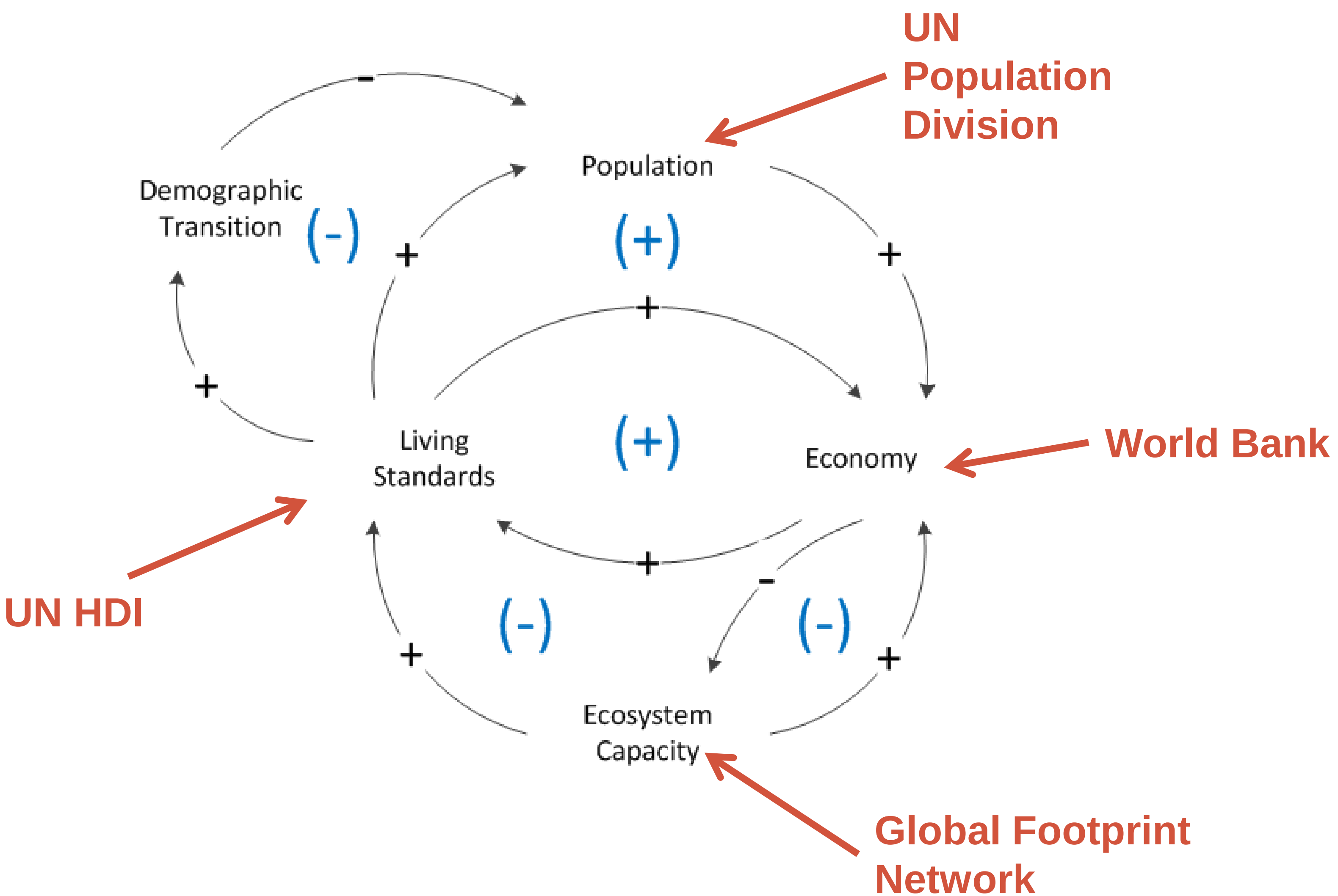
Source: WWF Living Planet Report 2010

# Ecological Footprint history

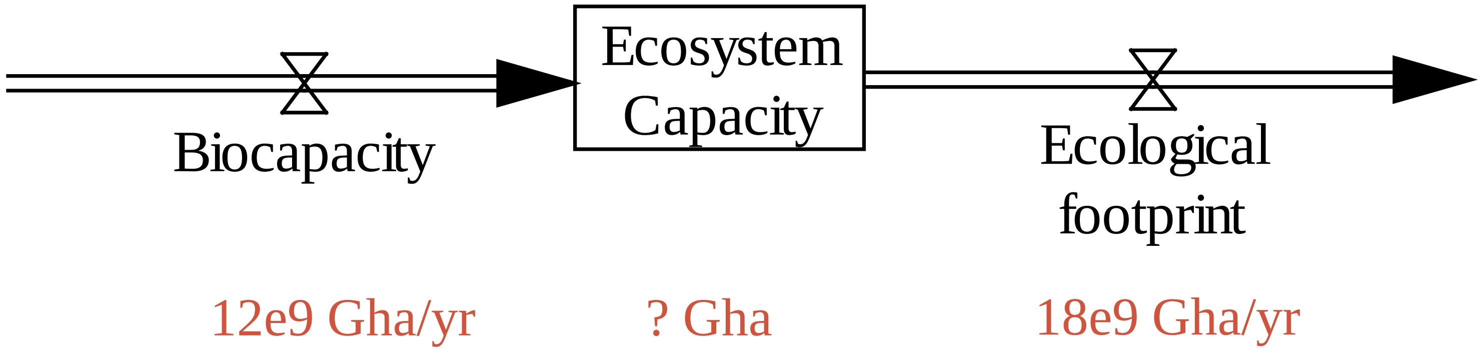



Source: Global Footprint Network

# Model data


UN Population Division
Population
Demographic Transition
(-)
+
(+)
+
+
Living Standards
(+)
Economy
World Bank
-
+
UN HDI
+
(-)
-
(-)
+
Ecosystem Capacity
Global Footprint Network
+

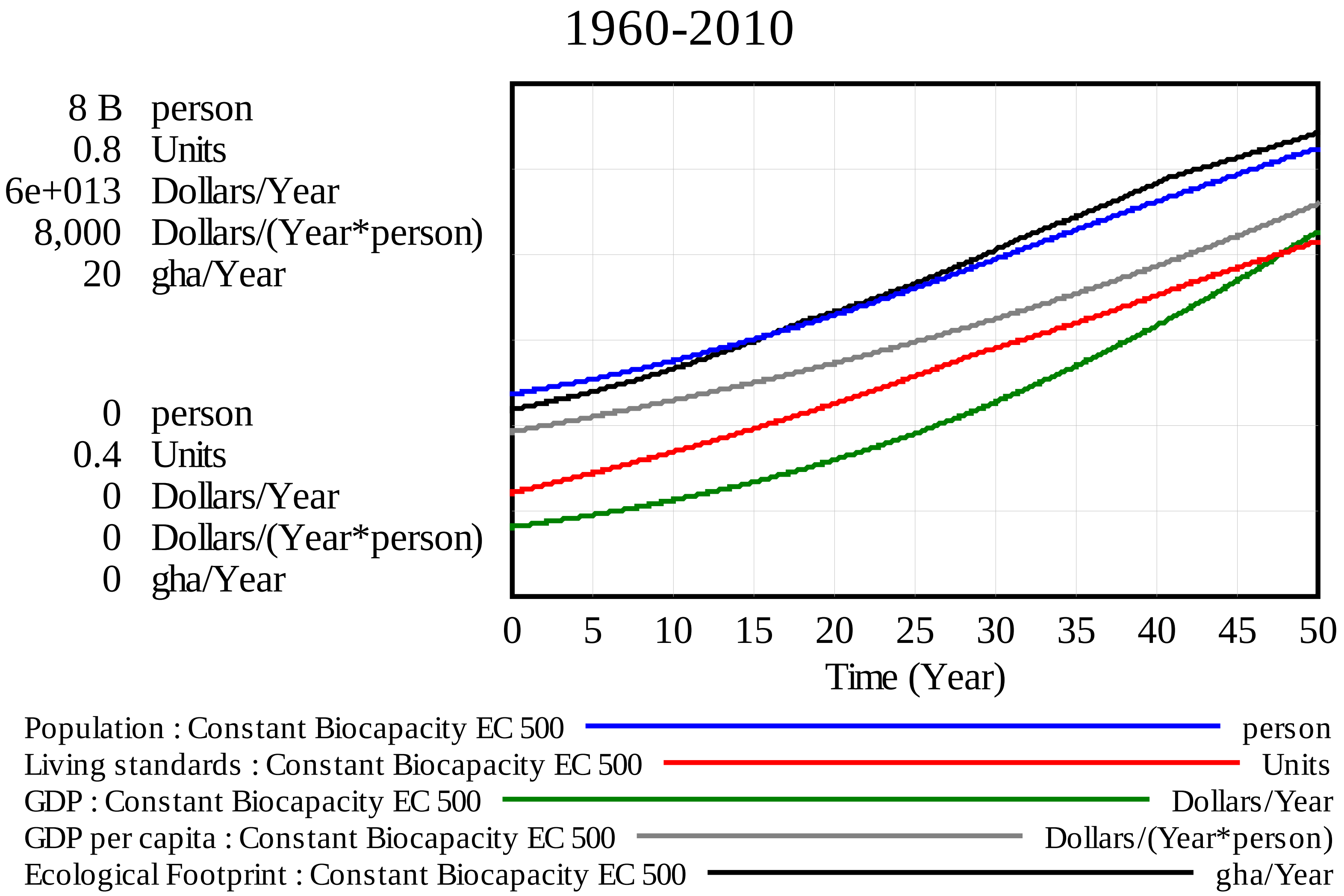
# Ecosystem Capacity




Depletion = 6e9 Gha/yr
EF ratio = 1.5

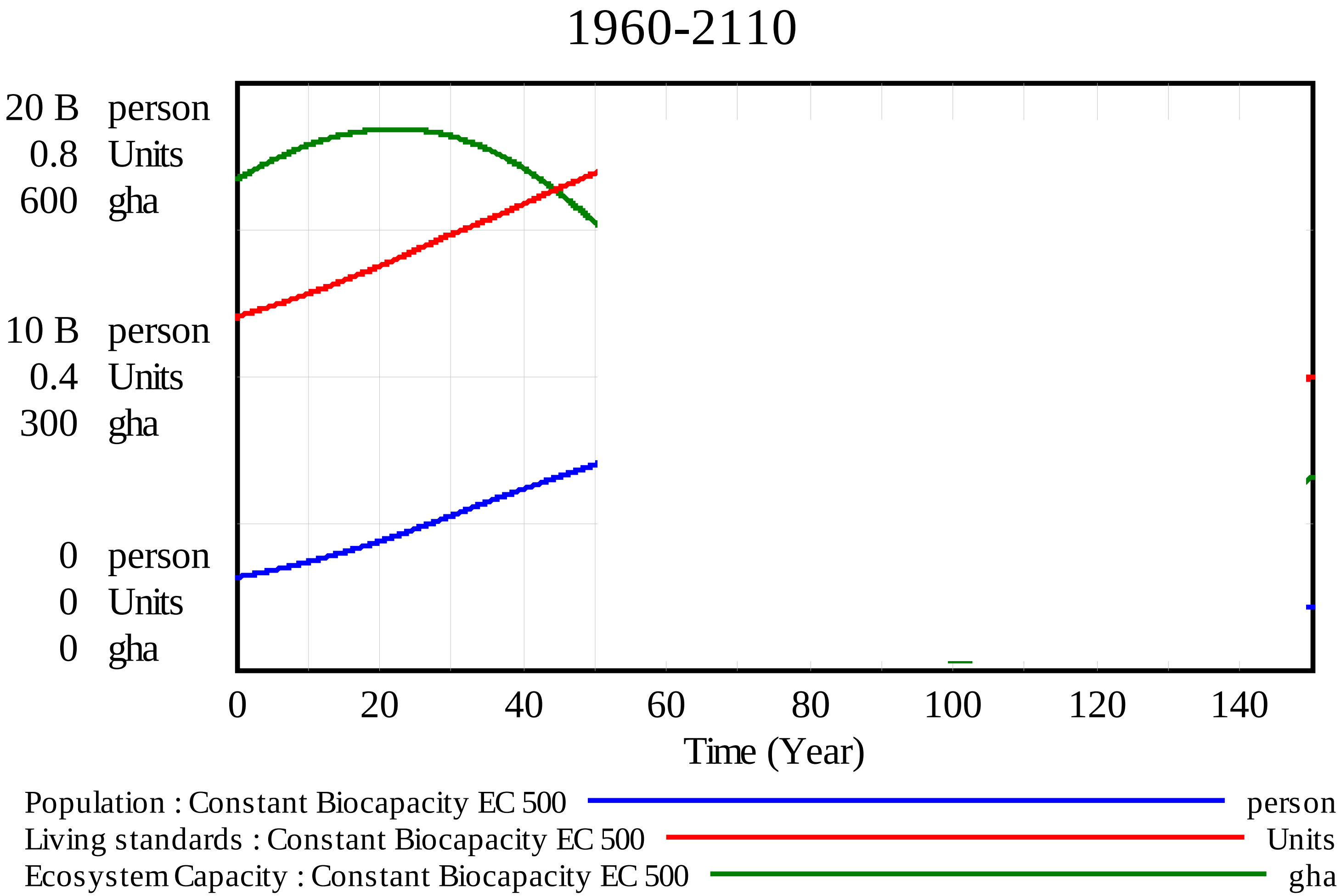
How deep is the well?

# Model run 1


1960-2010
8 B person
0.8 Units
6e+013 Dollars/Year
8,000 Dollars/(Year*person)
20 gha/Year
0 person
0.4 Units
0 Dollars/Year
0 Dollars/(Year*person)
0 gha/Year
0 5 10 15 20 25 30 35 40 45 50
Time (Year)
Population : Constant Biocapacity EC 500 person
Living standards : Constant Biocapacity EC 500 Units
GDP : Constant Biocapacity EC 500 Dollars/Year
GDP per capita : Constant Biocapacity EC 500 Dollars/(Year*person)
Ecological Footprint : Constant Biocapacity EC 500 gha/Year

# Model run 2

100 yrs ES capacity at depletion rate of 5 Gha/yr



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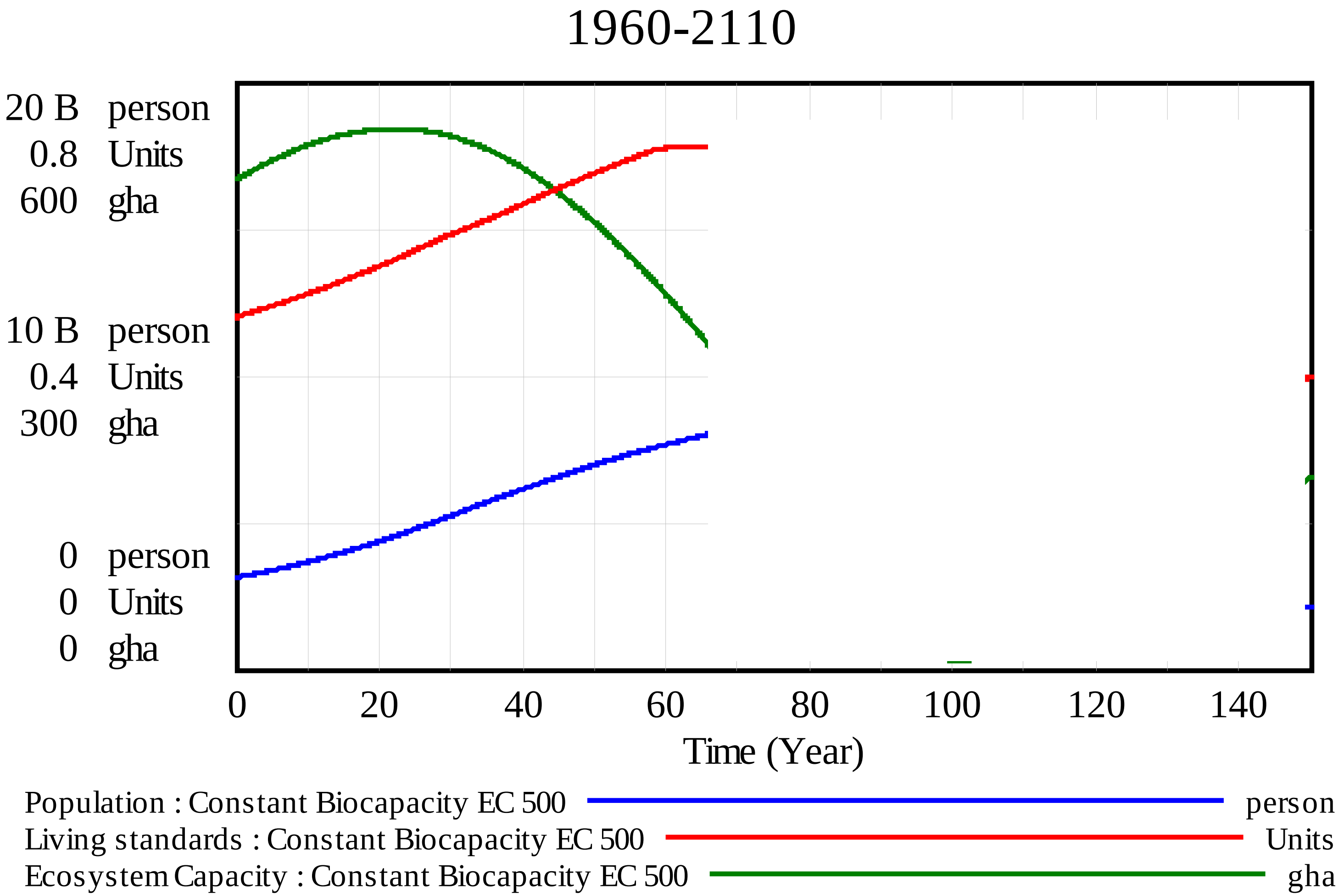

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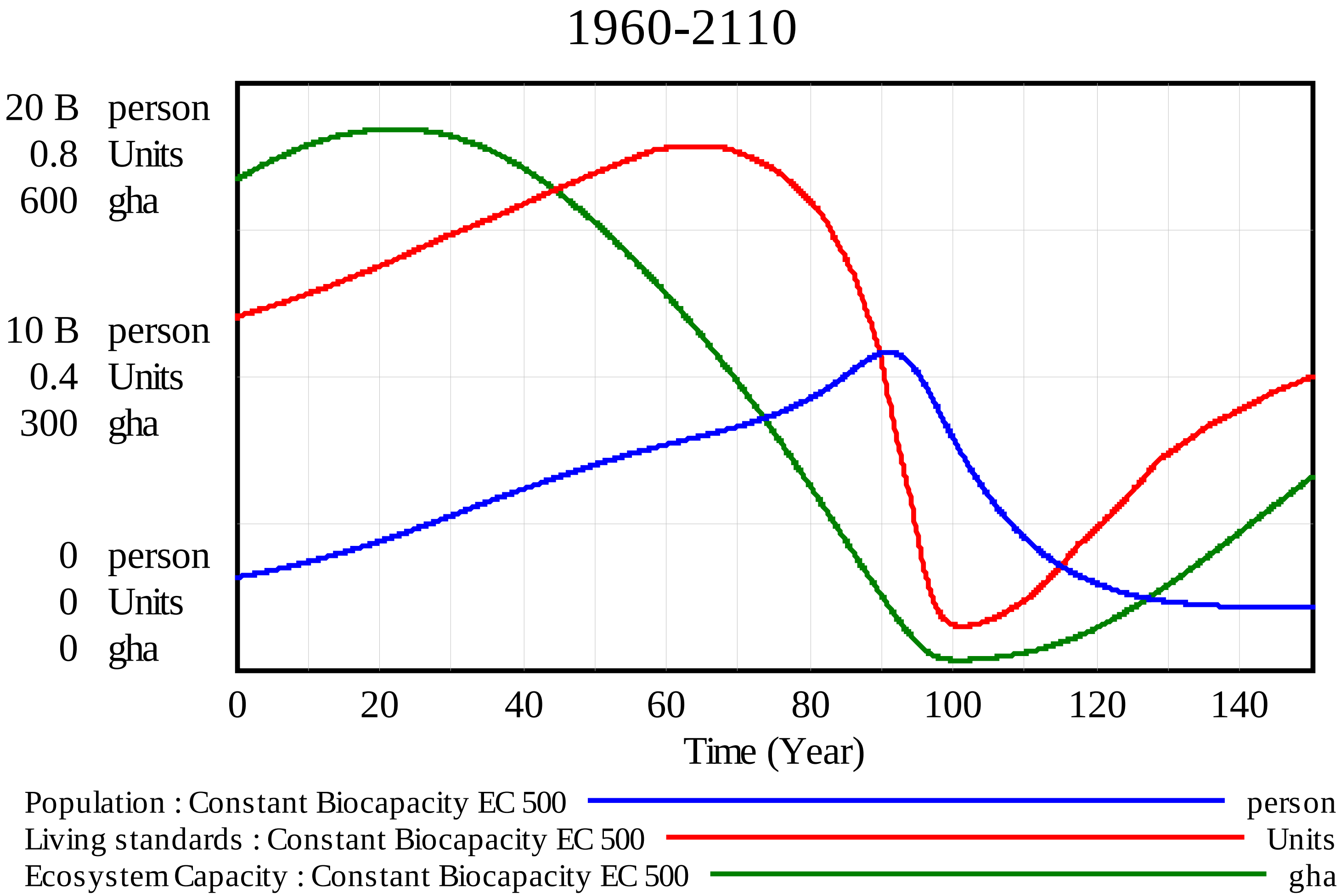
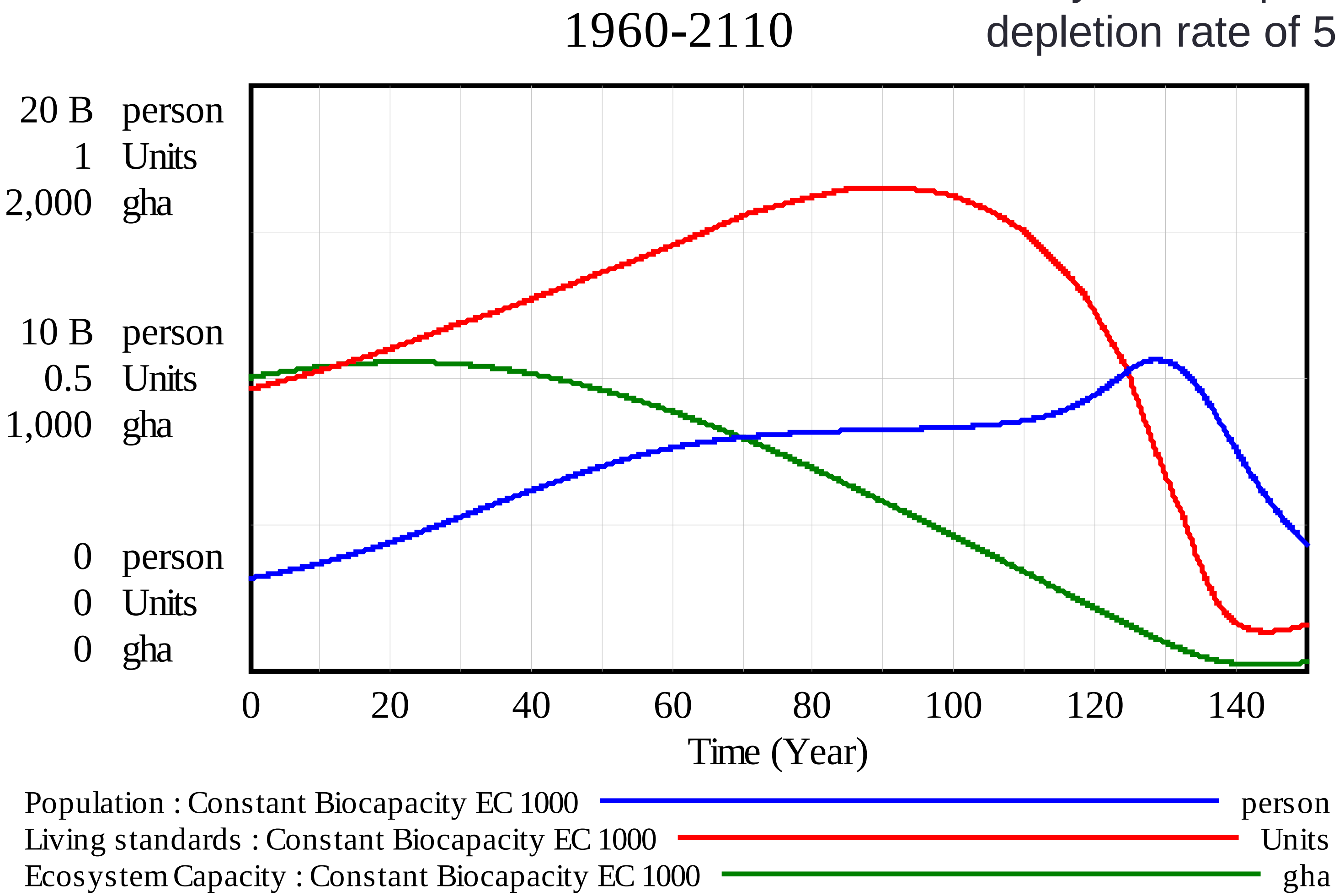
100 yrs ES capacity at depletion rate of 5 Gha/yr



# Model run 3 – Double ES capacity

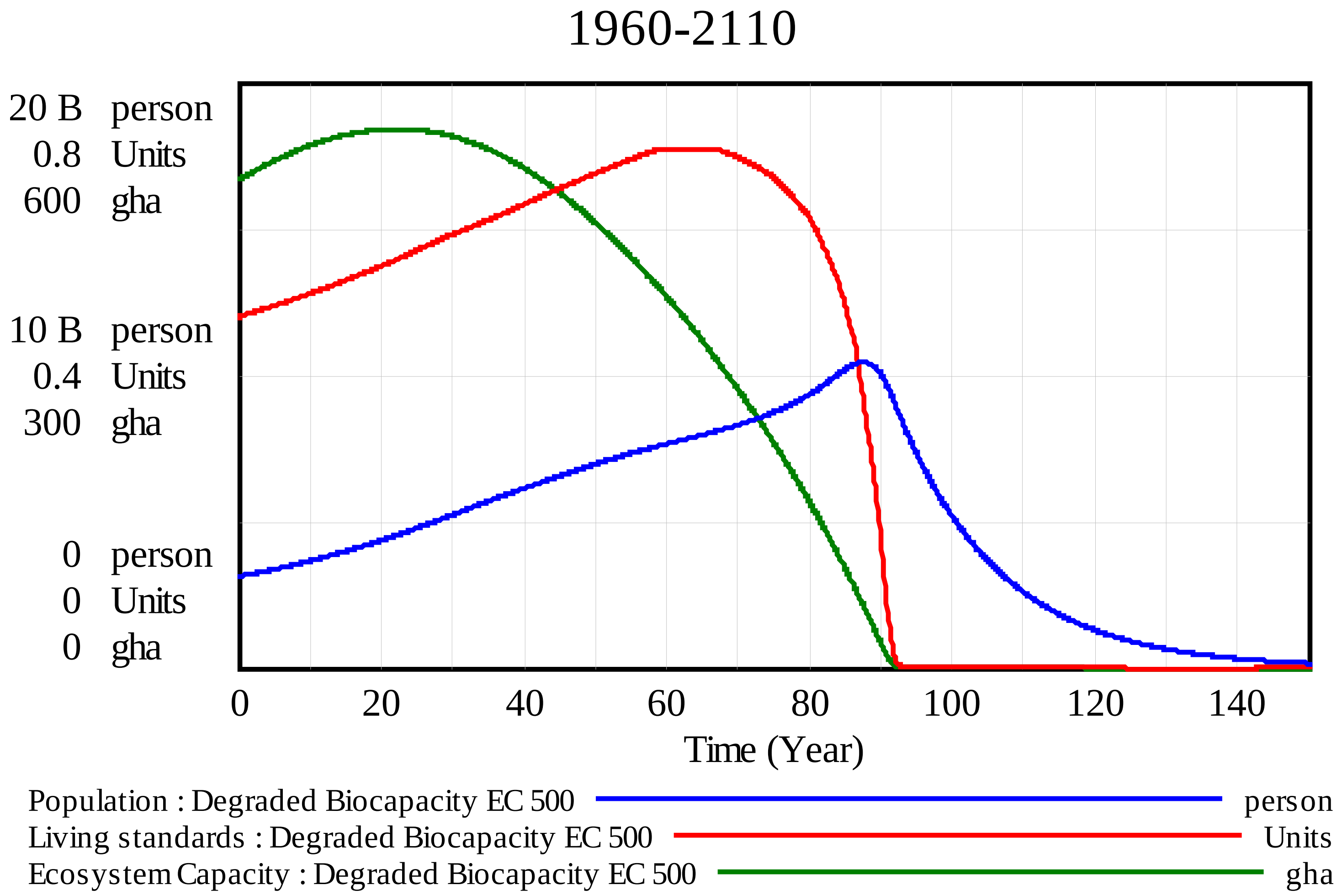
200 yrs ES capacity at depletion rate of 5 Gha/yr



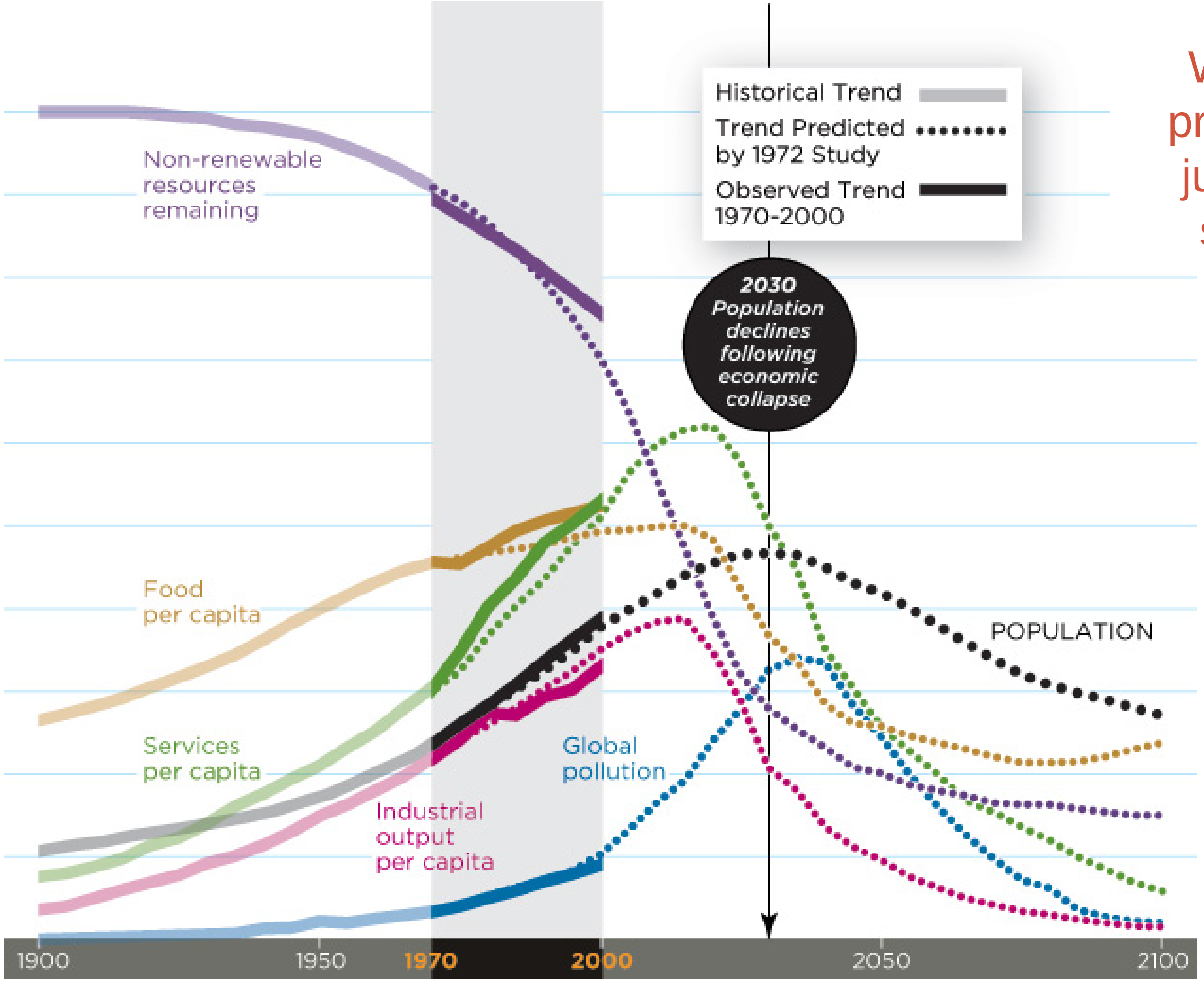
# What if the resource base is degraded?

- Model to date assumes Biocapacity is constant and unaffected by the depletion of Ecosystem Capacity, ie
- The regenerative capacity of the system remains intact
- Many examples of overshoot do not exhibit this behaviour, eg
  - Conversion to grasslands from forest
  - Desertification

# Model run 4 – Degraded ES capacity



# Limits to Growth 1972




Wrong! No predictions – just several scenarios

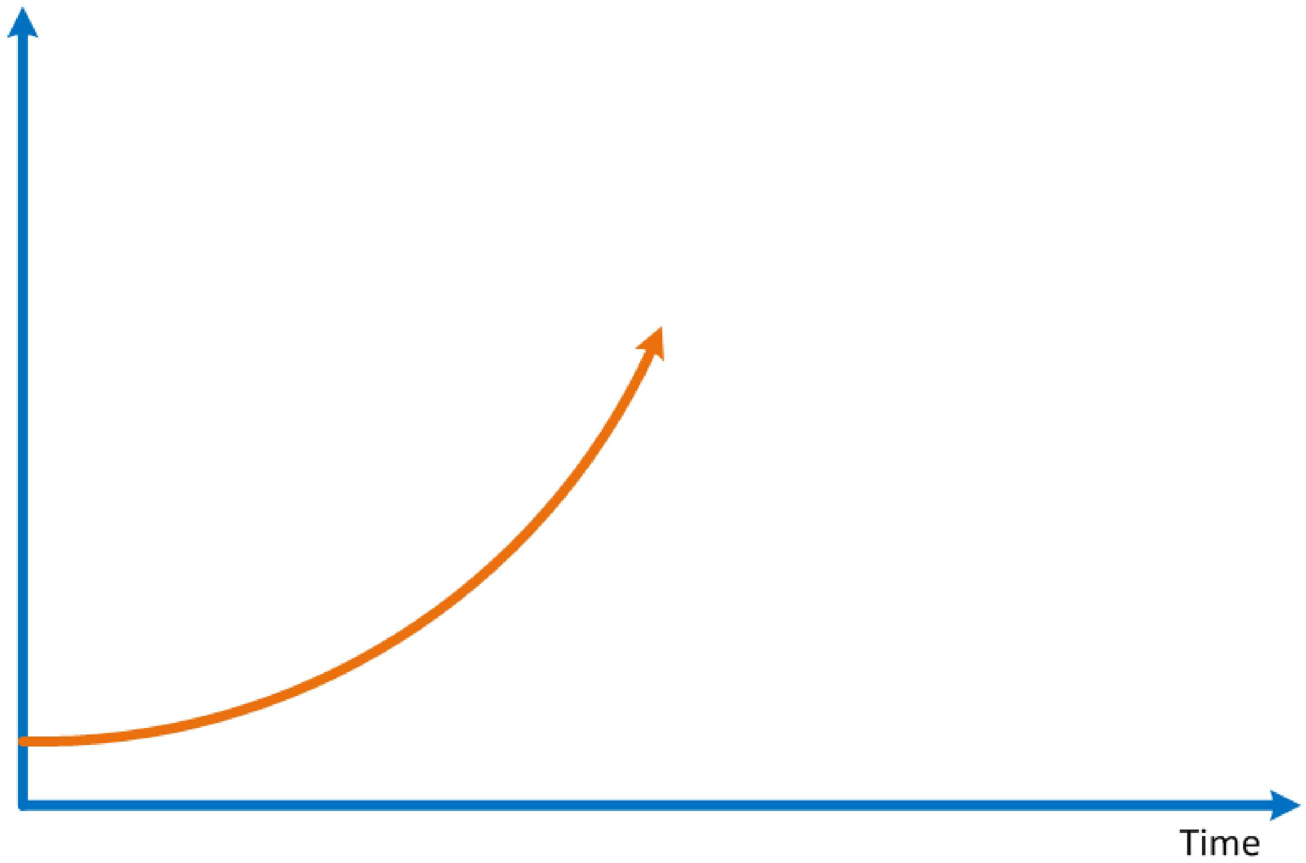
Source: Smithsonian.com and G.Turner

# Why does this happen?

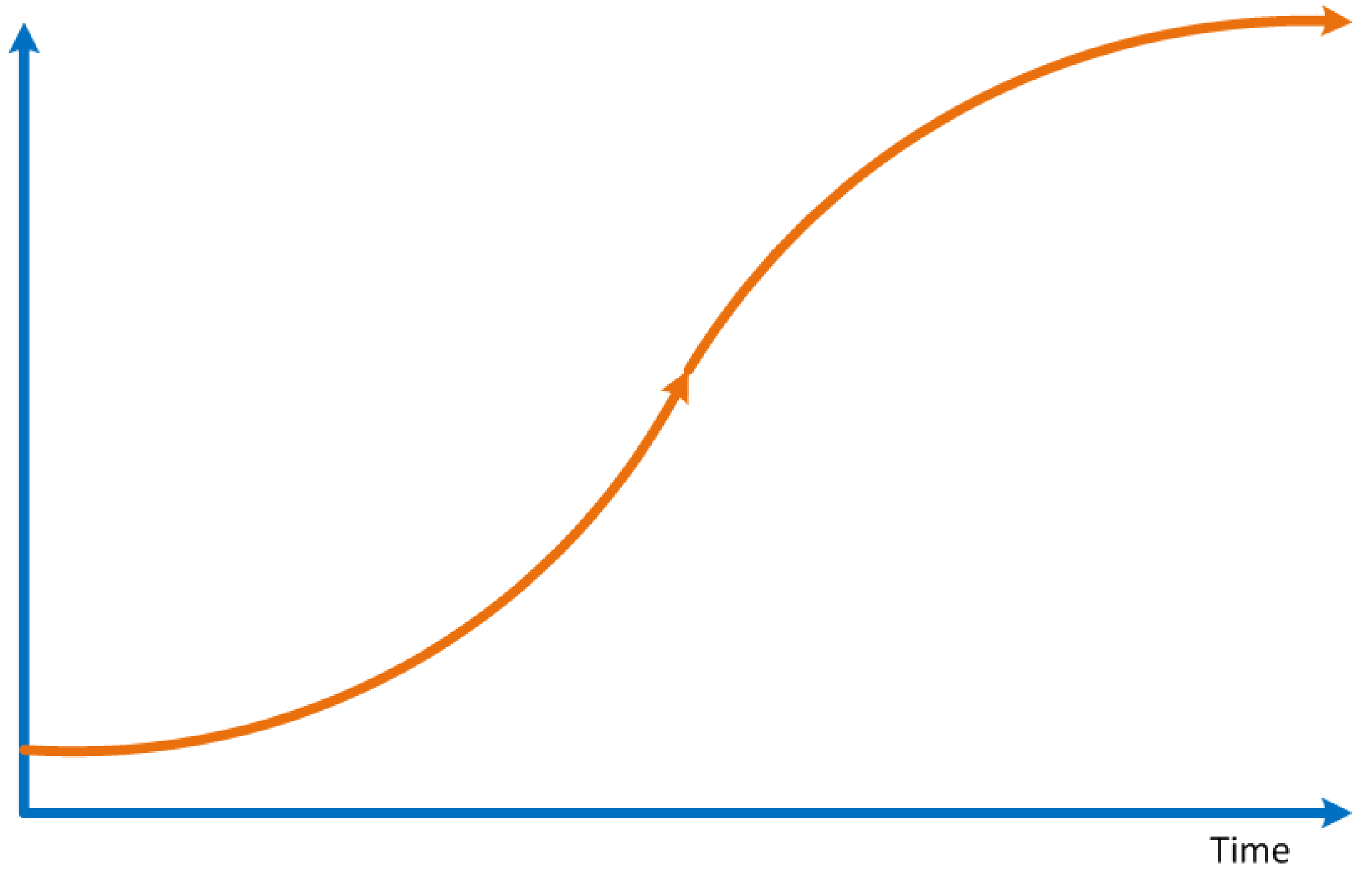
# System dynamics 101

- All systems comprise combinations of reinforcing and balancing loops
- Limits to Growth archetypes are all around us:
  - Predator / prey relationships
  - The overshoot and collapse of the human population on Easter Island
  - Overgrazing in the Sahel region of Africa by cattle herders
  - Overfishing of the oceans by fishermen
  - Business growth limited by the size of the potential market

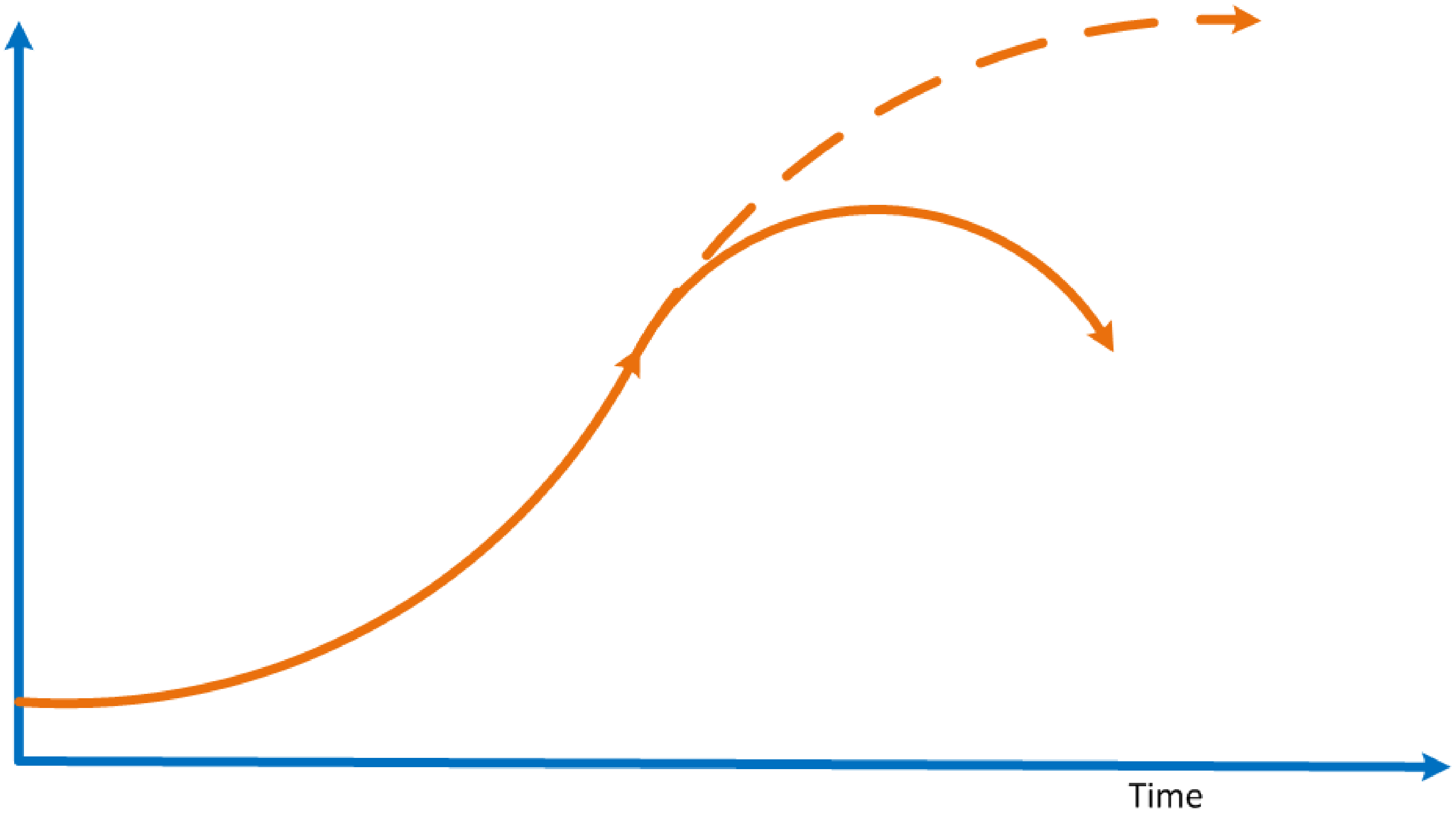
# In the beginning - exponential growth



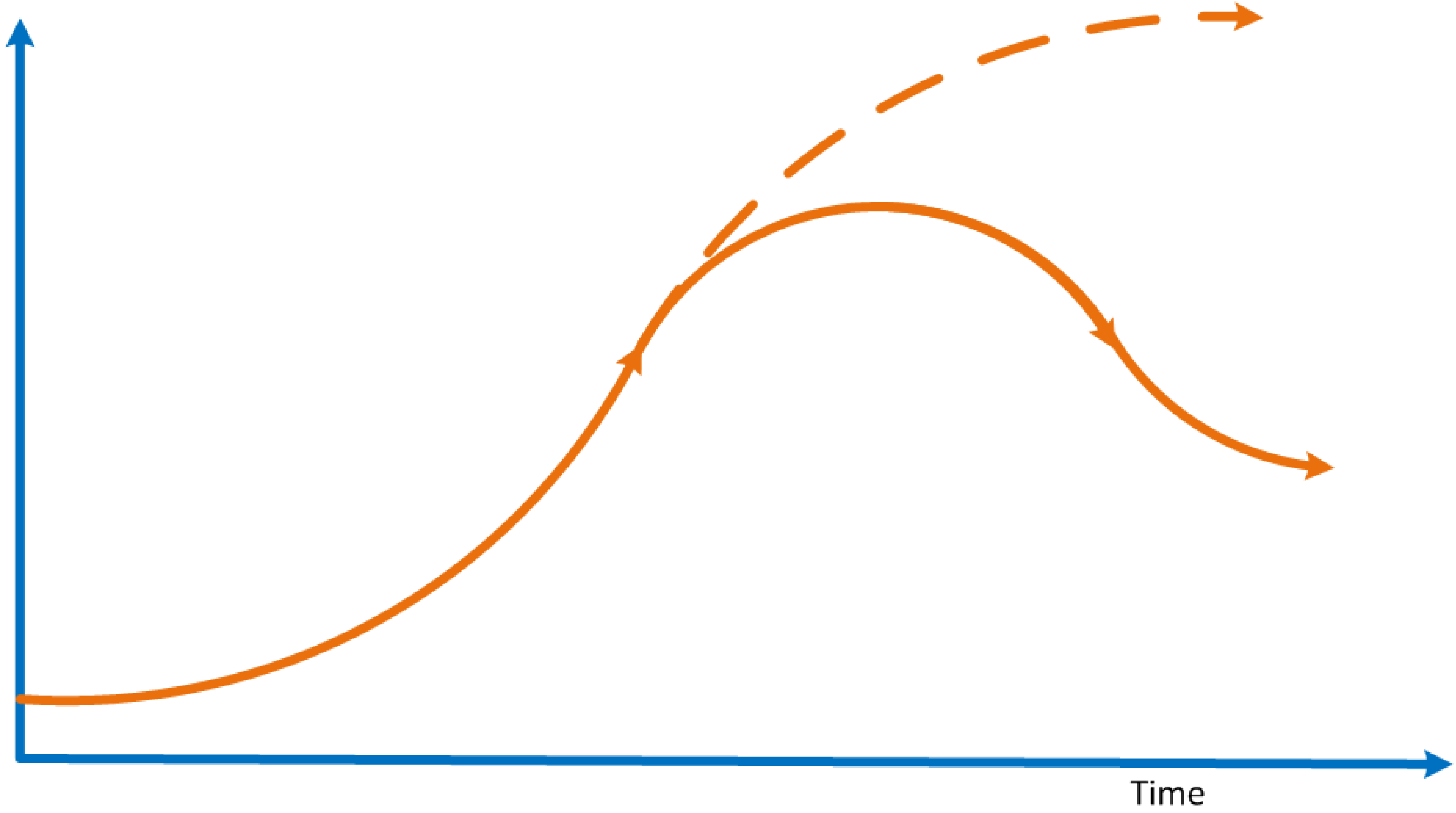
# Smooth transition to equilibrium, or



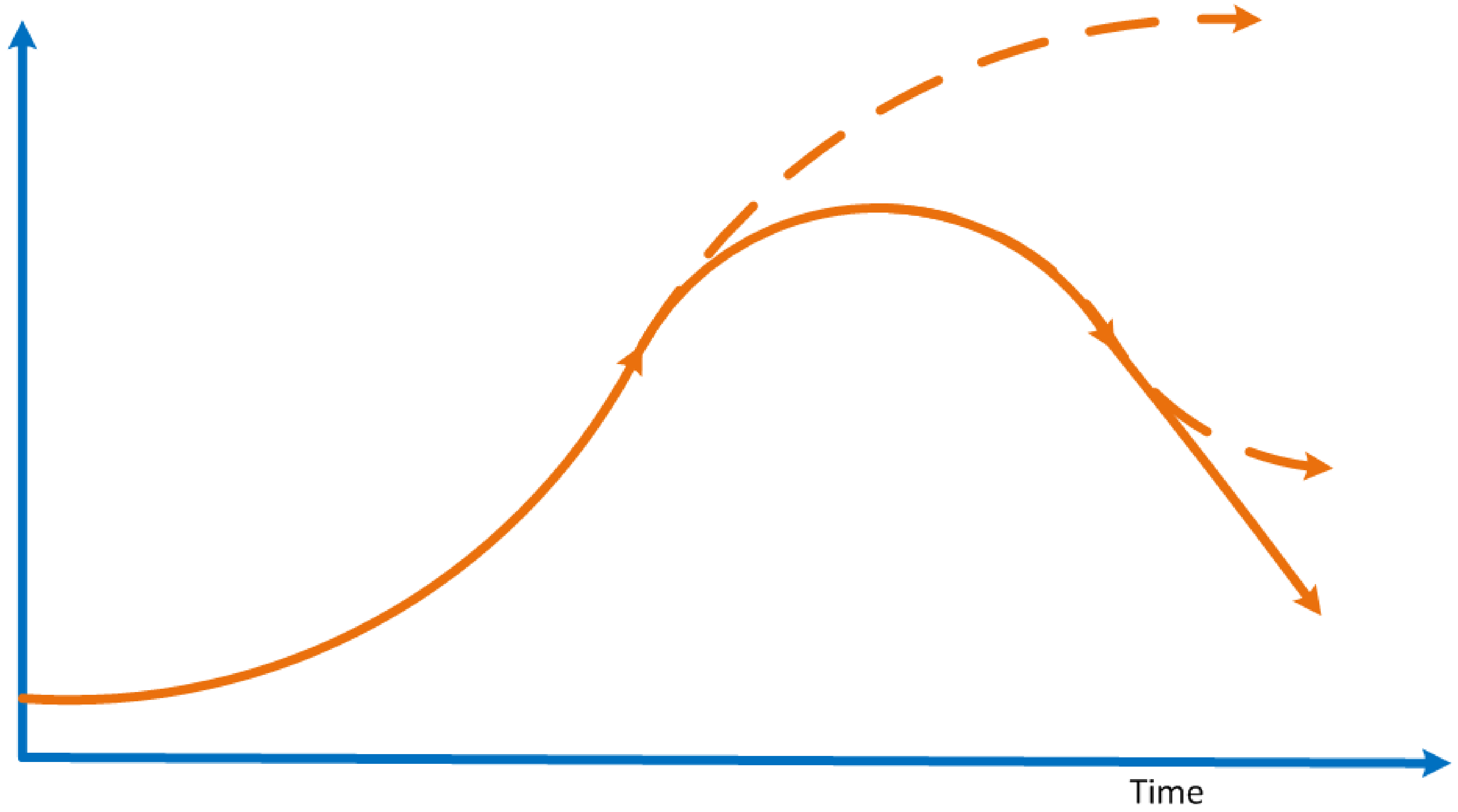
# Overshoot, followed by …..



# Transition to a lower level equilibrium, or

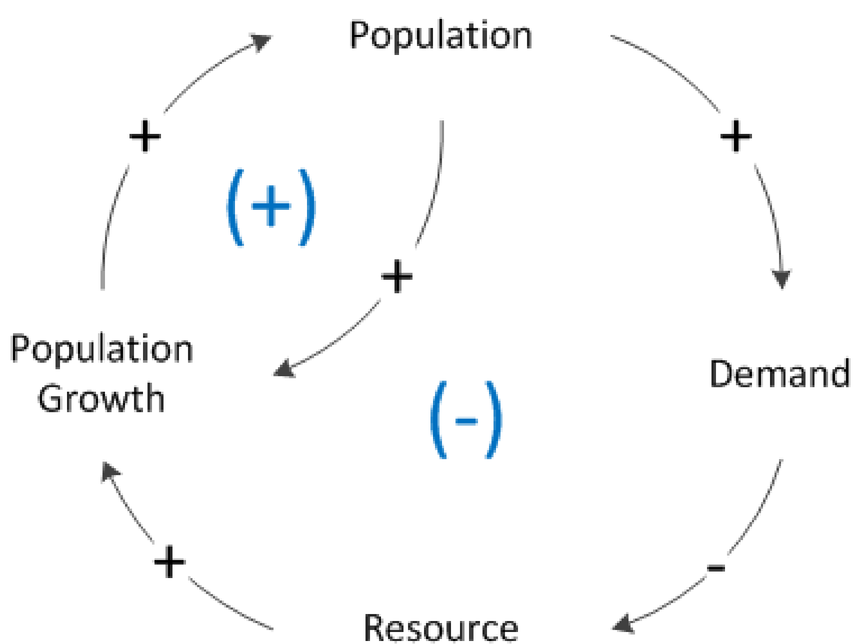


# Collapse

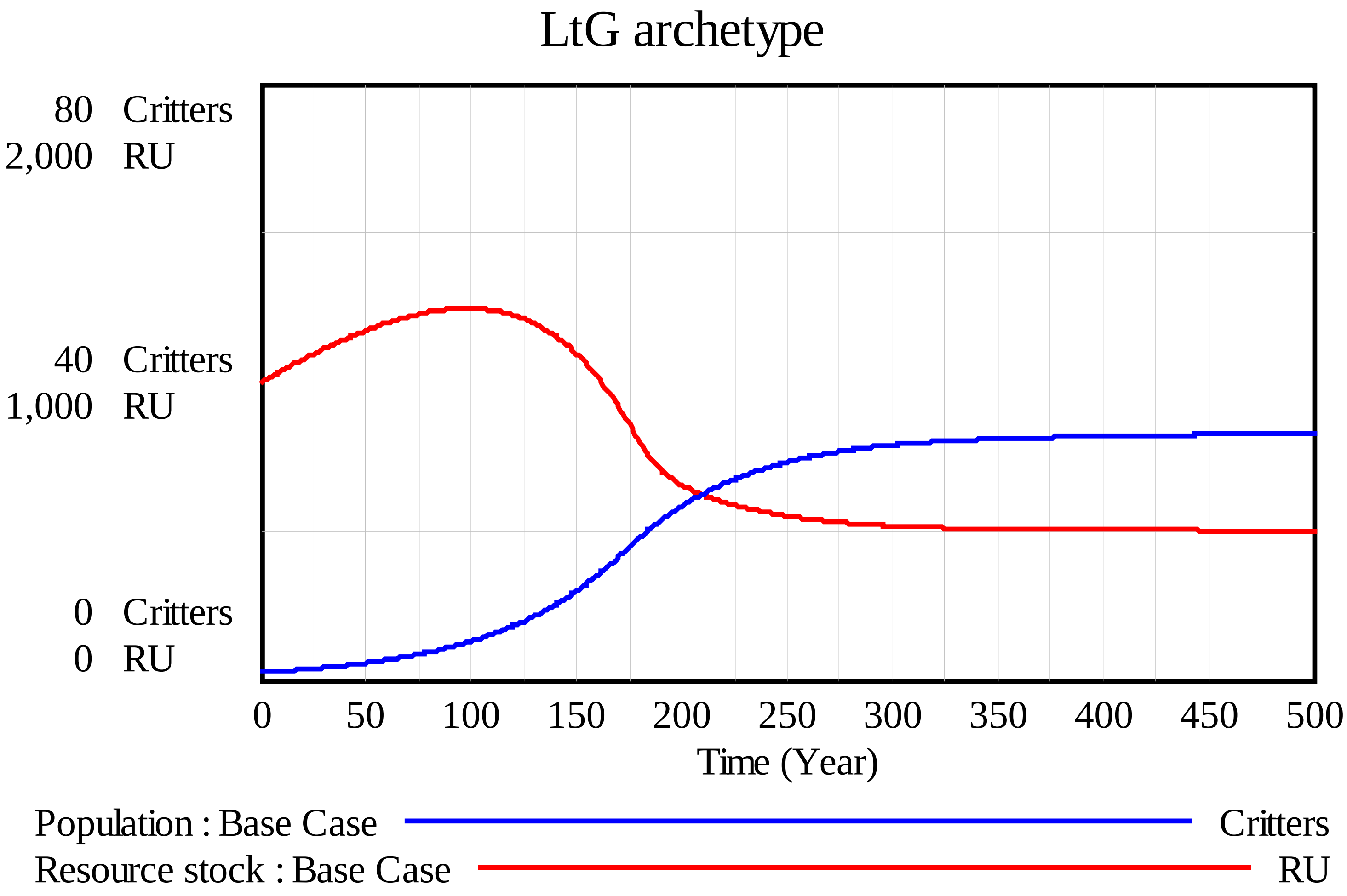


# A really simple example

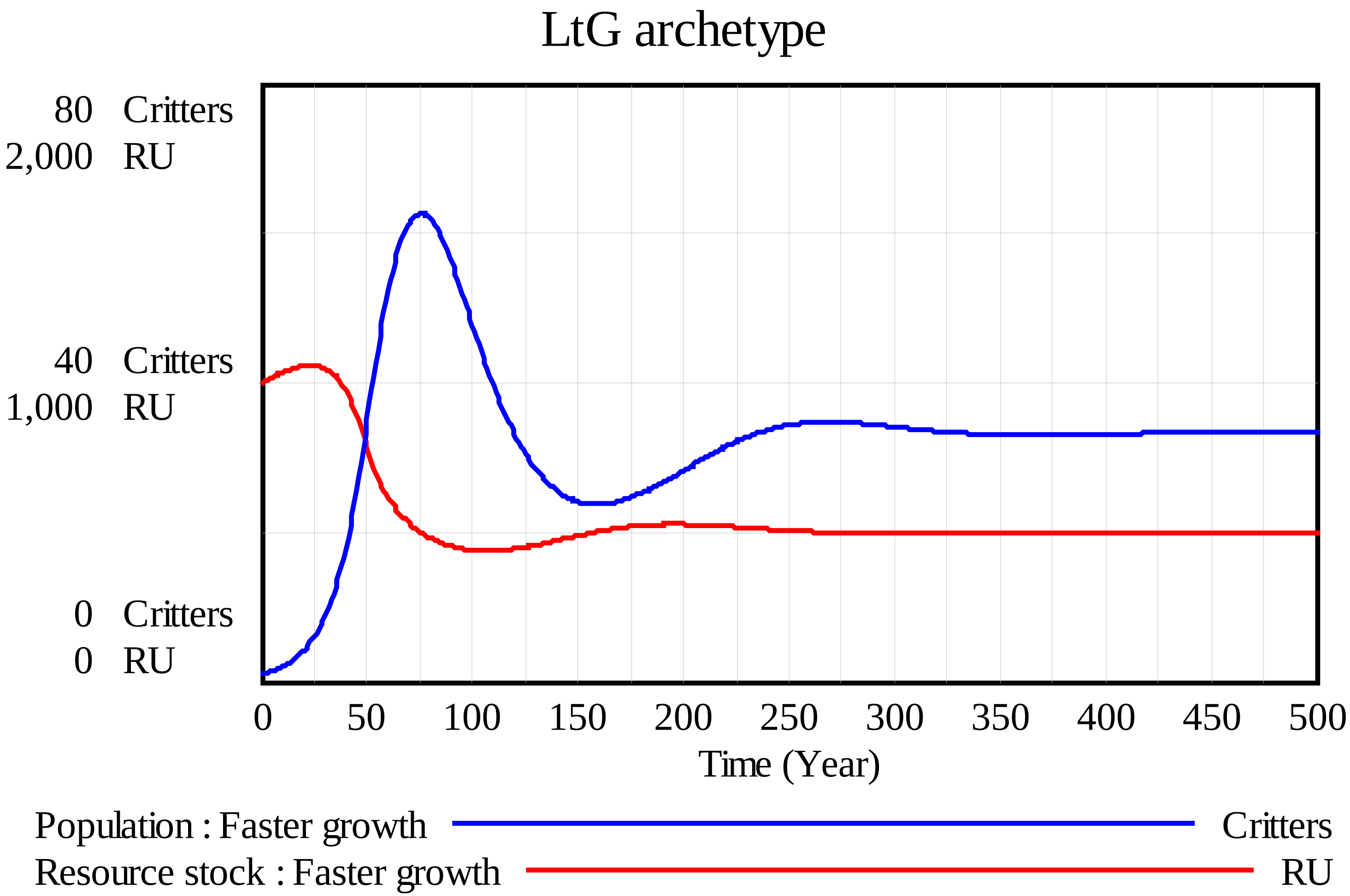
# Population growth – finite resource



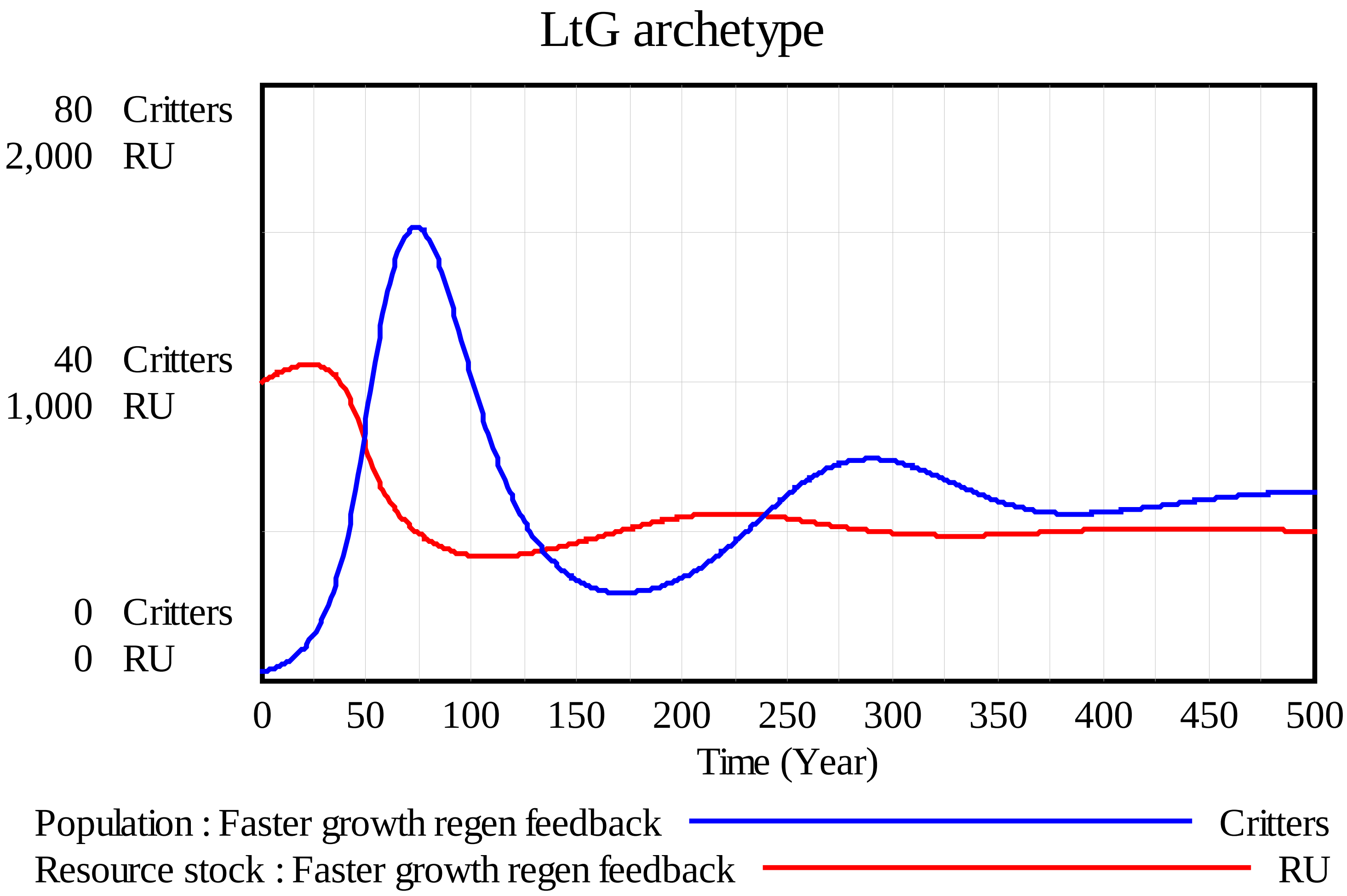
# Base case – smooth transition to equilibrium



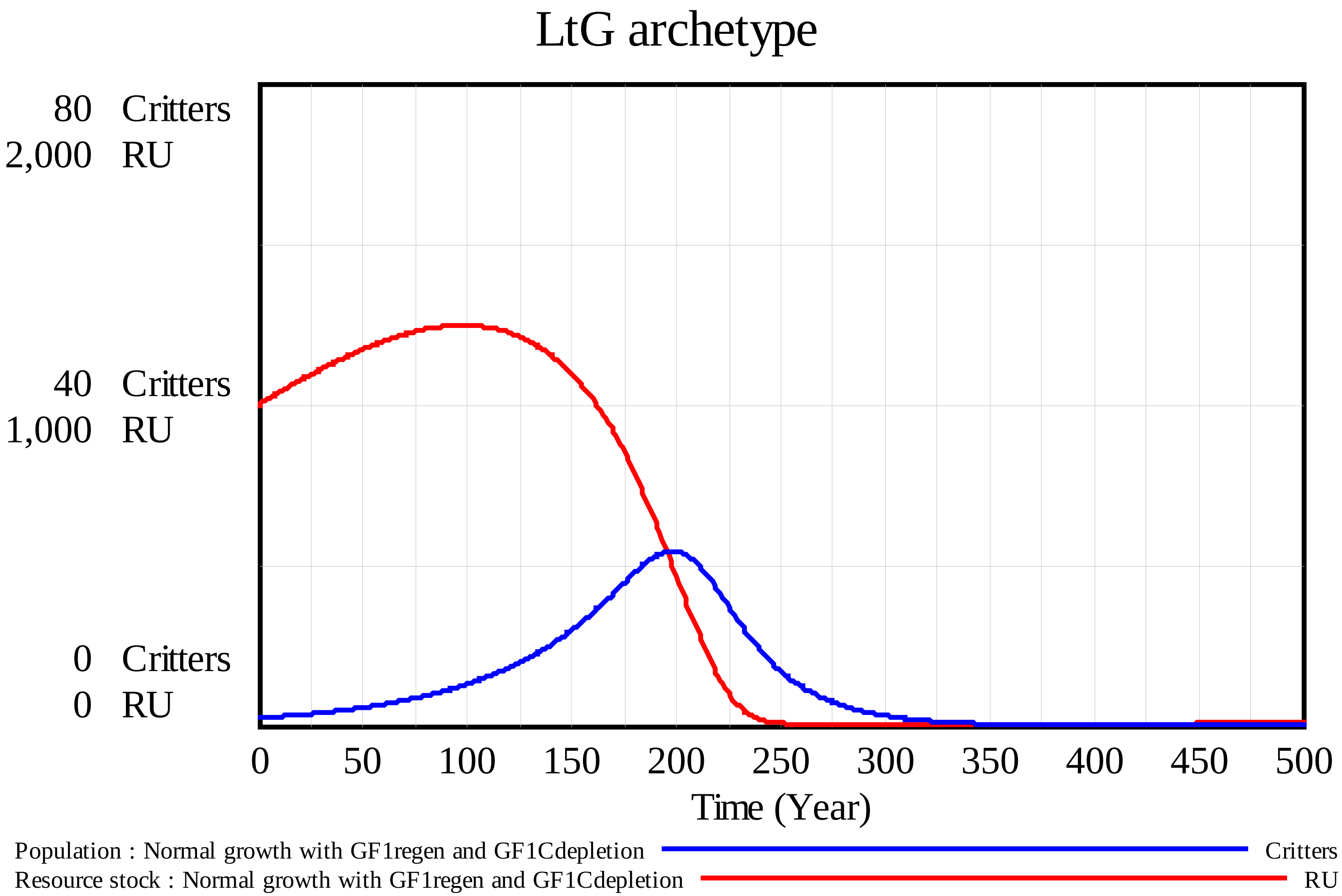
# Faster growth rate



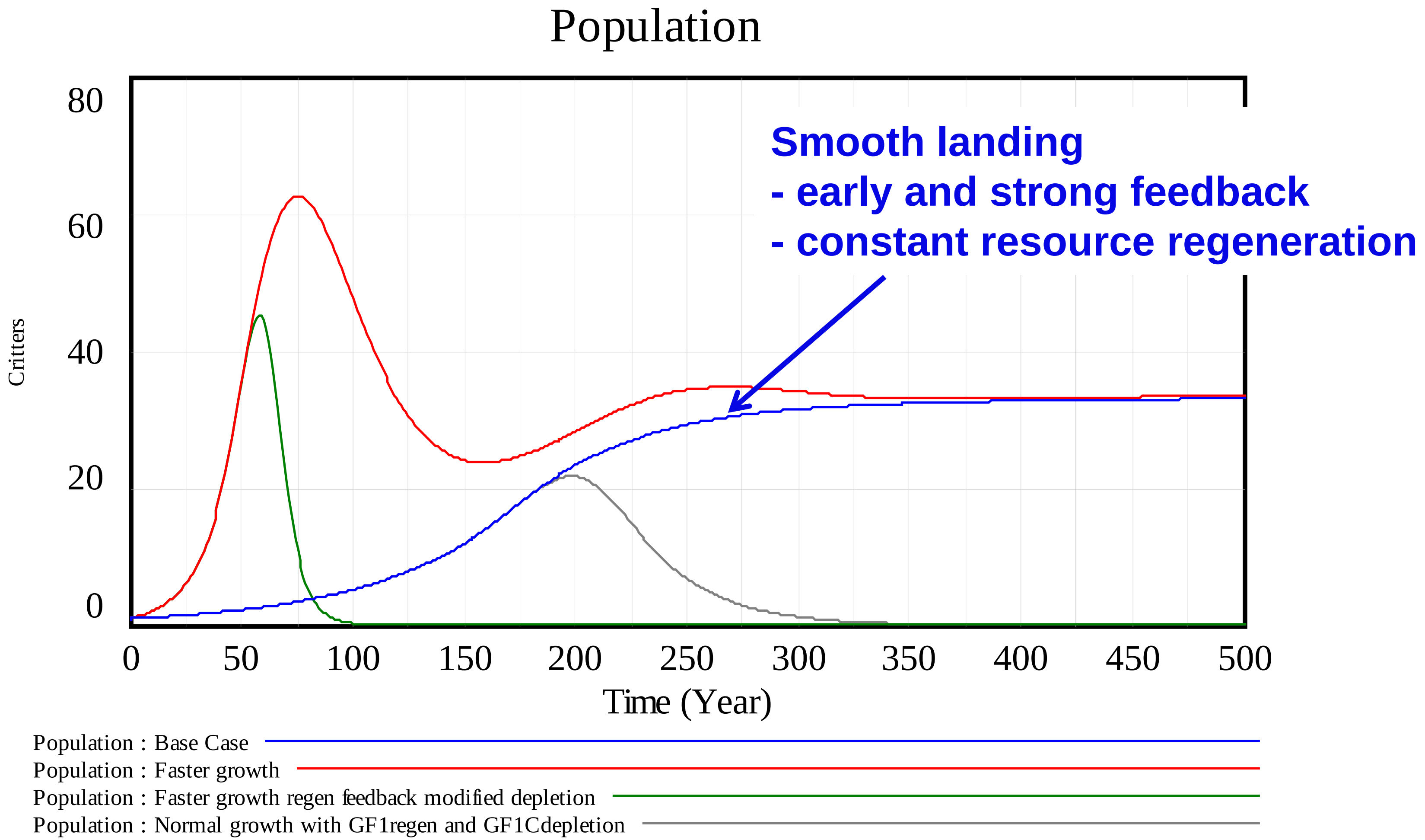
# Faster growth rate with degrading regeneration



# Original growth rate with faster degrading regeneration



# What causes these differences in behaviour?



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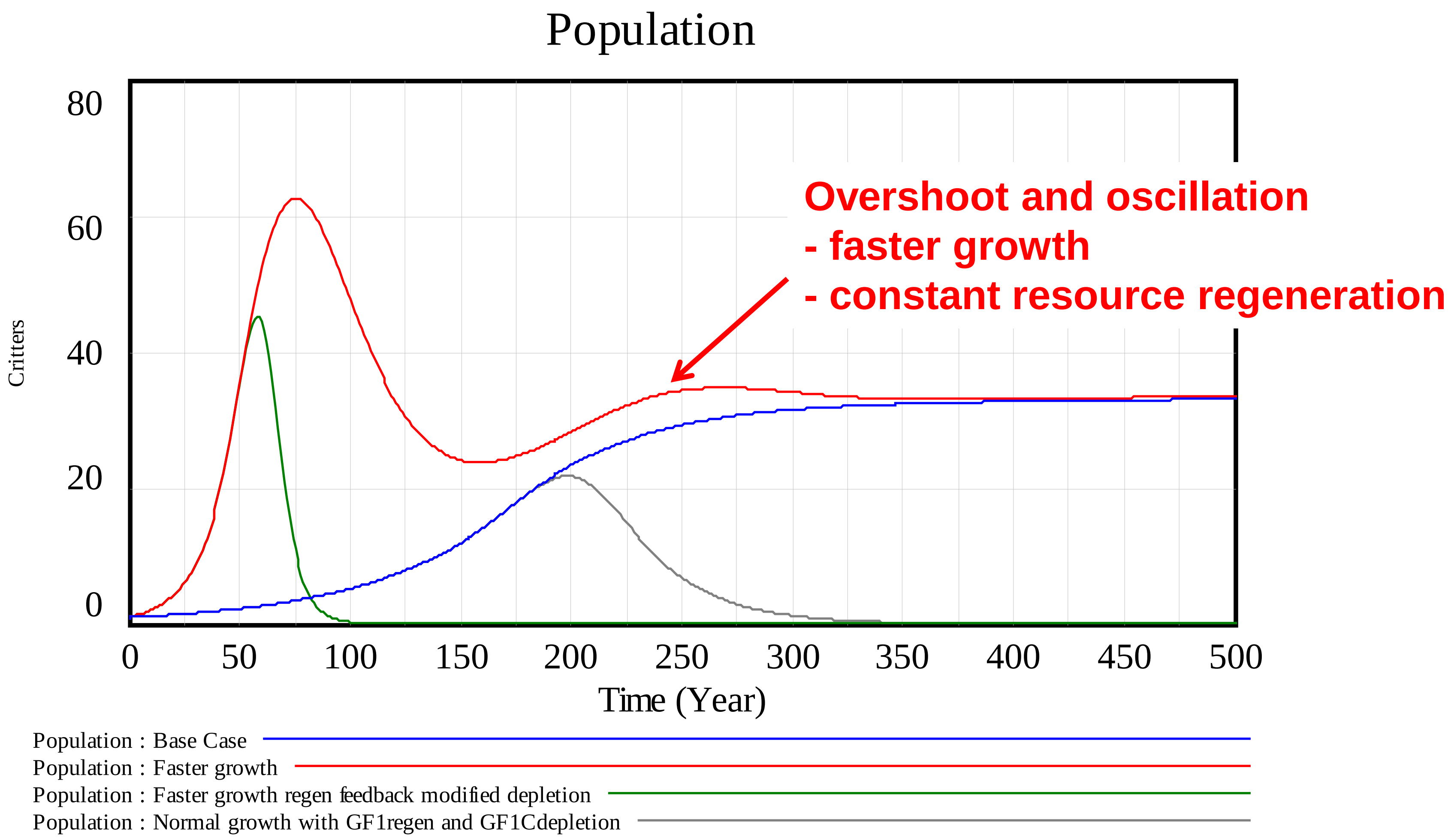

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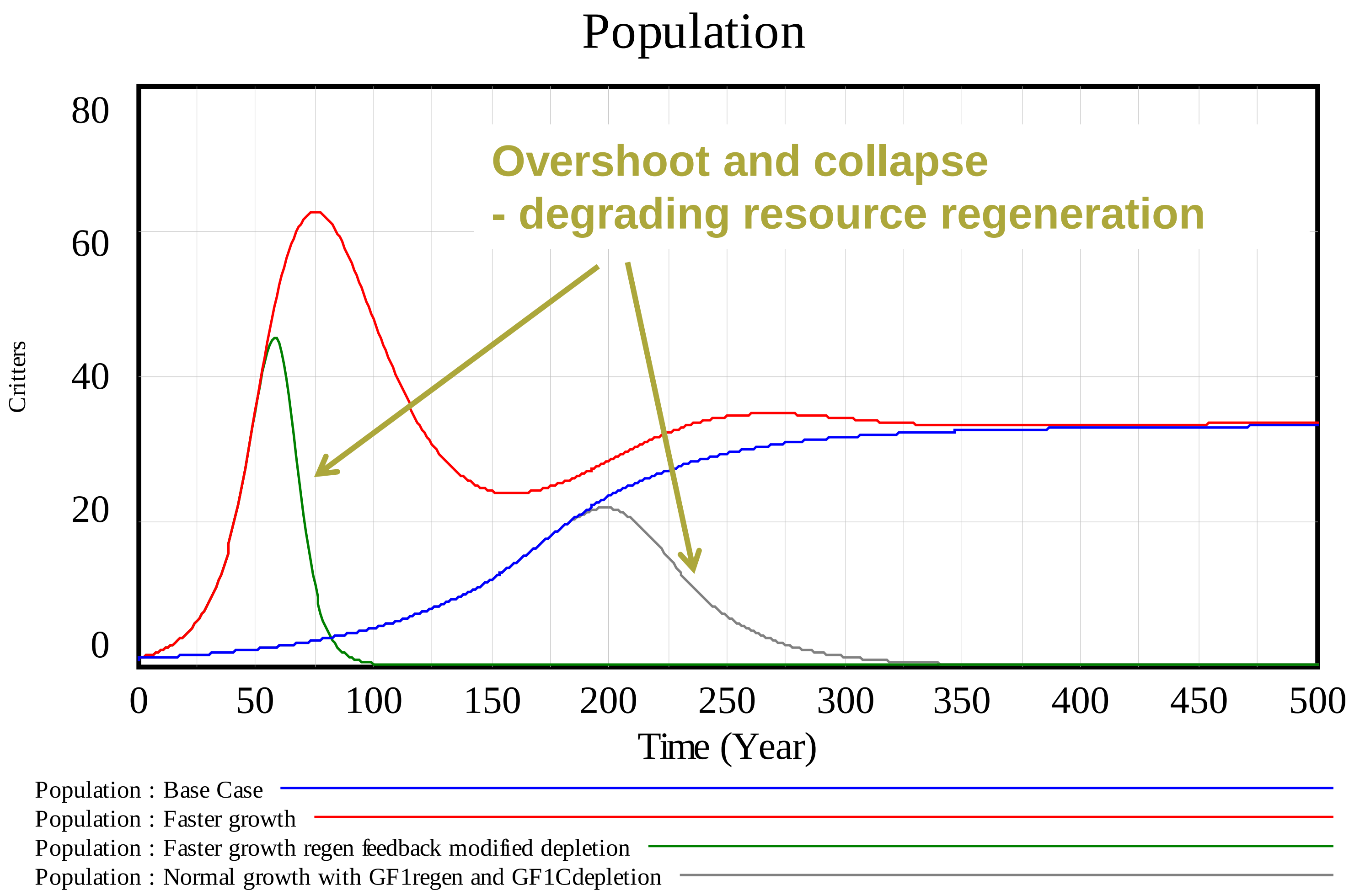


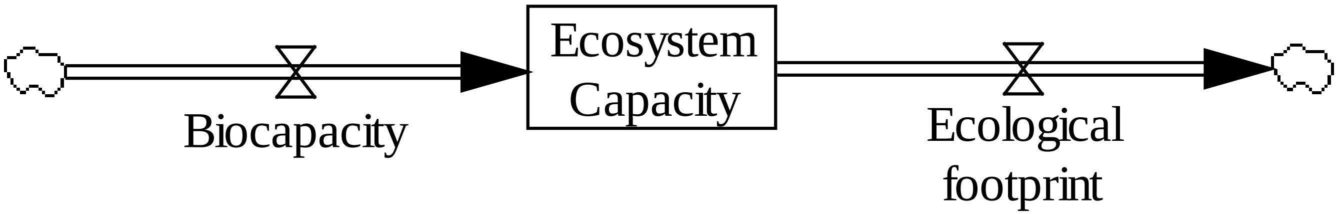
# Technology is no answer

*“It makes no difference how large the resource base is: to the extent technology and markets alleviate scarcity today, the result is more growth tomorrow, until the resource is again insufficient, some other resource becomes scarce, or some other environmental problem arises.*

*Solve these, and growth continues until some other part of the carrying capacity is lost, some other limit reached. As long as growth is the driving force there can be no purely technological solution to the problem of scarcity.”*

Source: Sterman 2011

# Everything is dependent on these flows



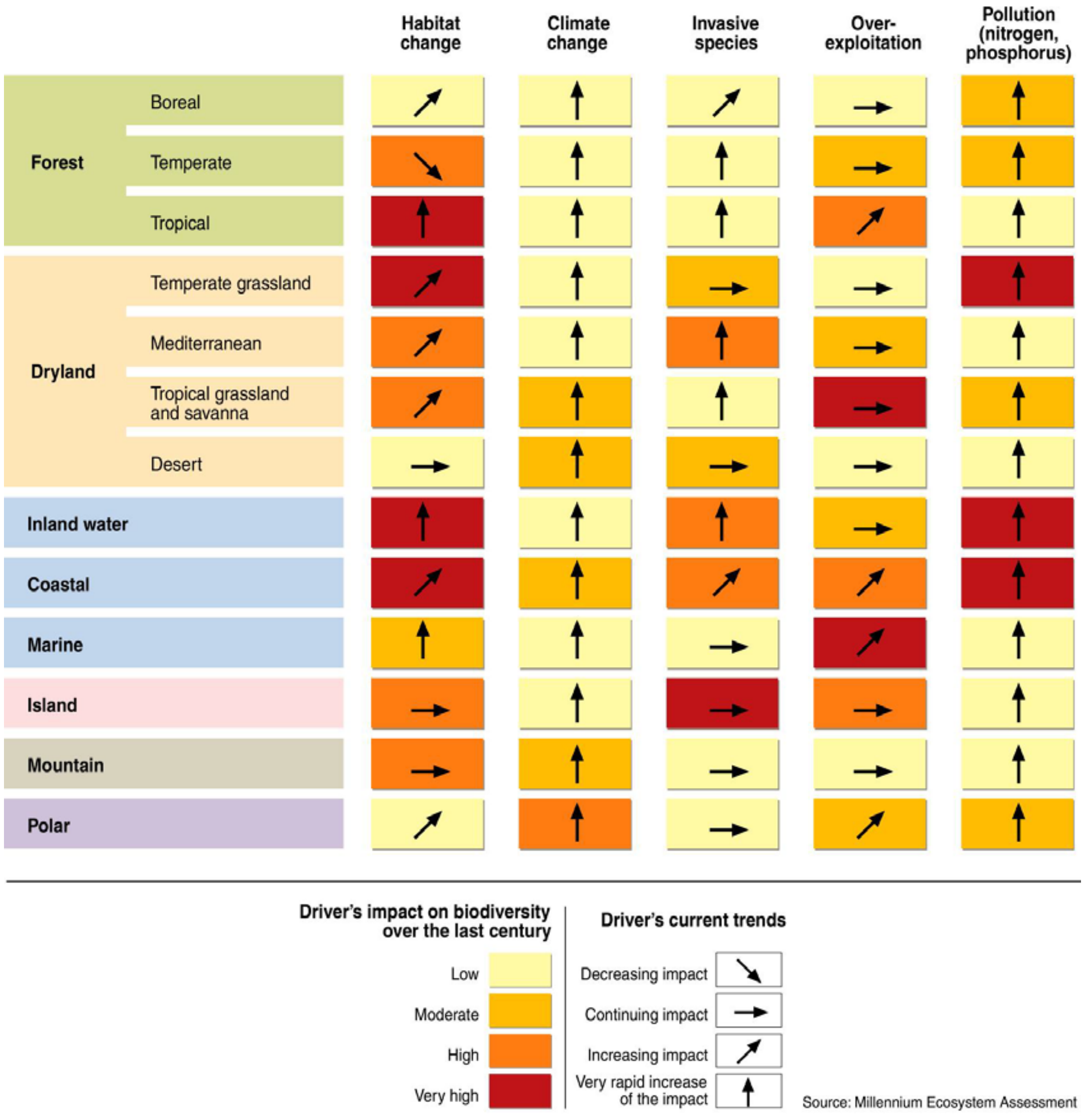

Resilience requires a dynamic equilibrium that matches ecological footprint to bio-capacity

Sustainability requires that this equilibrium occurs at a level that provides adequate ecosystem services to ensure human wellbeing

***Enduring human wellbeing***

# So where are we now?

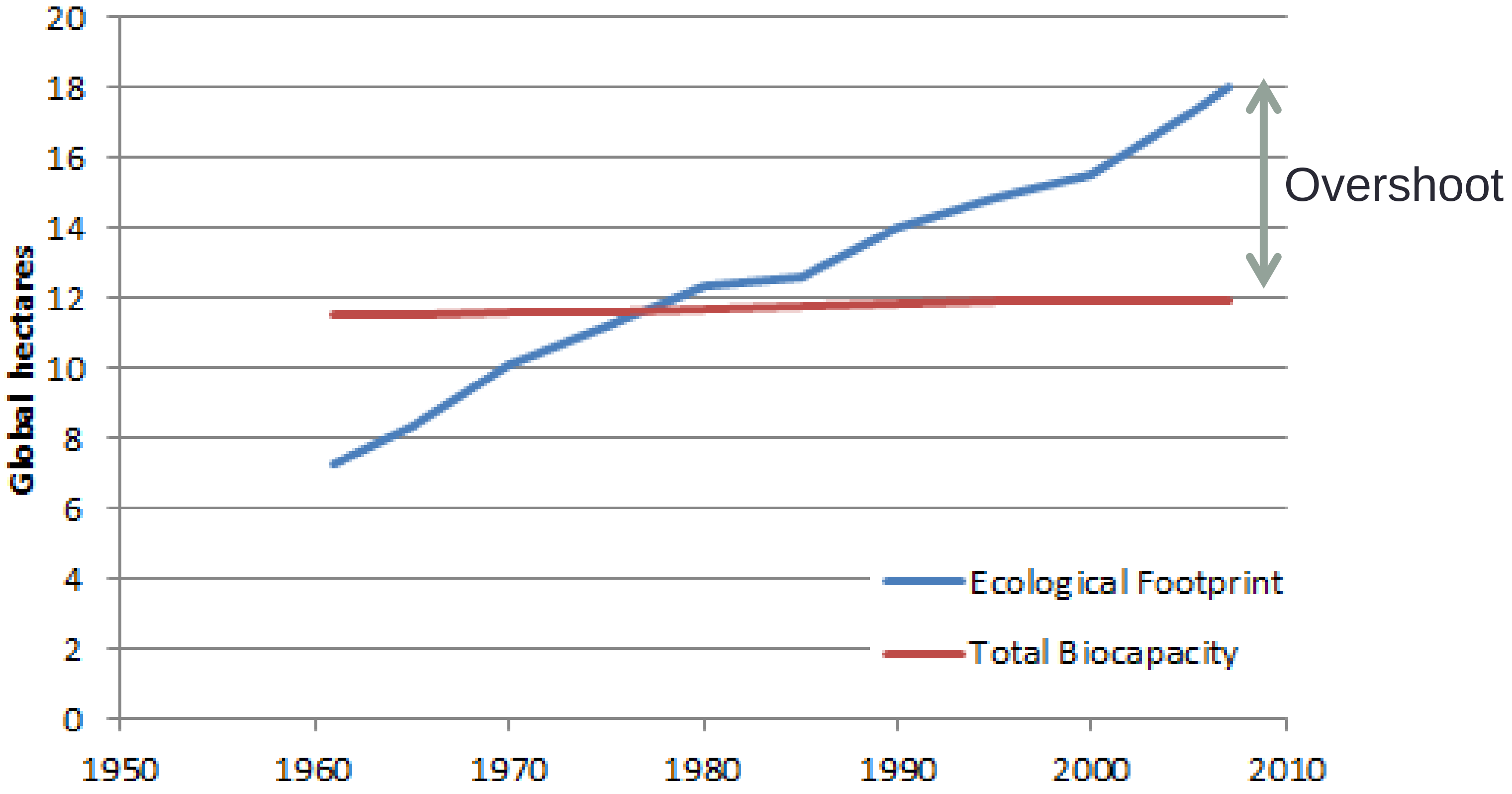
# Direct drivers growing in intensity




- Most direct drivers of degradation in ecosystem services remain constant or are growing in intensity in most ecosystems

Source: Millennium Ecosystem Assessment

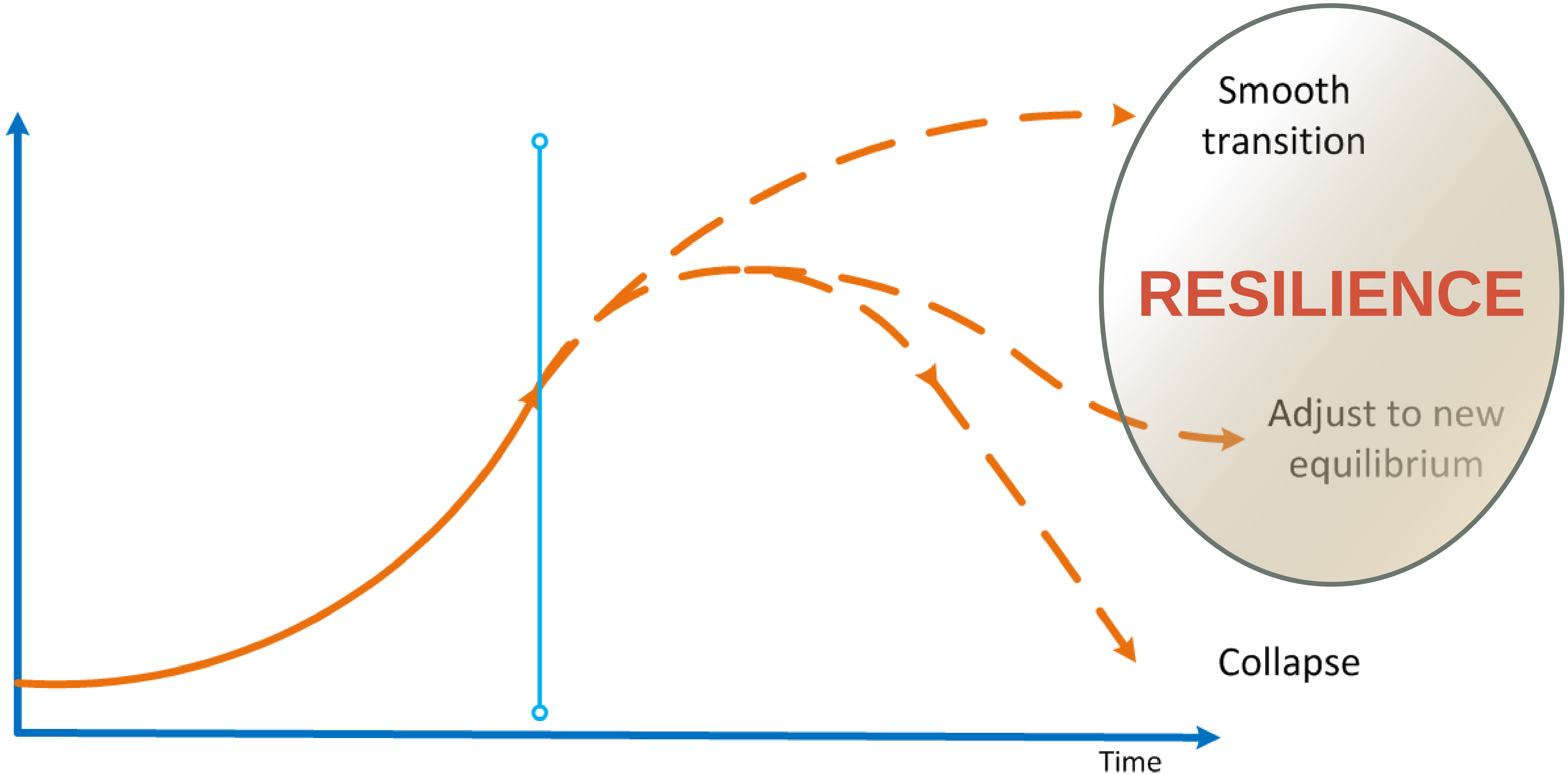
# Back to the Ecological Footprint




Too late for a smooth transition

Source: WWF Living Planet Report 2010

# Too late for a smooth transition



# Threats to resilience – non linear change


Rockström, J., W. Steffen, K. Noone, Å. Persson, F. S. Chapin, III, E. Lambin, T. M. Lenton, M. Scheffer, C. Folke, H. Schellnhuber, B. Nykvist, C. A. De Wit, T. Hughes, S. van der Leeuw, H. Rodhe, S. Sörlin, P. K. Snyder, R. Costanza, U. Svedin, M. Falkenmark, L. Karlberg, R. W. Corell, V. J. Fabry, J. Hansen, B. Walker, D. Liverman, K. Richardson, P. Crutzen, and J. Foley. 2009. Planetary boundaries:exploring the safe operating space for humanity. *Ecology and Society* **14**(2): 32. [online] URL: http://www.ecologyandsociety.org/vol14/iss2/art32/

*Research*

## Planetary Boundaries: Exploring the Safe Operating Space for Humanity

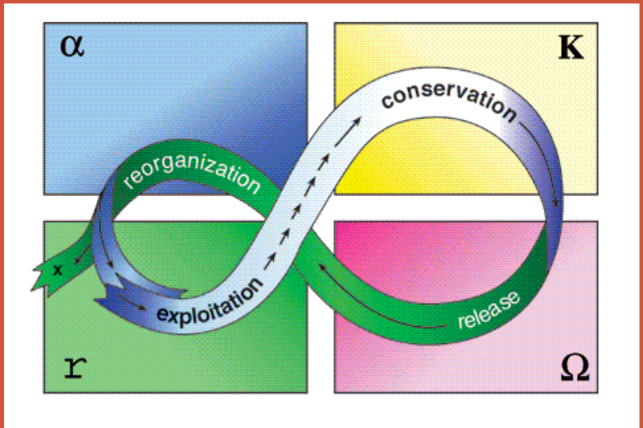
*Johan Rockström*[1,2], *Will Steffen*[1,3], *Kevin Noone*[1,4], *Åsa Persson*[1,2], *F. Stuart III Chapin*[5], *Eric Lambin*[6], *Timothy M. Lenton*[7], *Marten Scheffer*[8], *Carl Folke*[1,9], *Hans Joachim Schellnhuber*[10,11], *Björn Nykvist*[1,2], *Cynthia A. de Wit*[4], *Terry Hughes*[12], *Sander van der Leeuw*[13], *Henning Rodhe*[14], *Sverker Sörlin*[1,15], *Peter K. Snyder*[16], *Robert Costanza*[1,17], *Uno Svedin*[1], *Malin Falkenmark*[1,18], *Louise Karlberg*[1,2], *Robert W. Corell*[19], *Victoria J. Fabry*[20], *James Hansen*[21], *Brian Walker*[1,22], *Diana Liverman*[23,24], *Katherine Richardson*[25], *Paul Crutzen*[26], *and Jonathan Foley*[27]

Source: Ecology & Society 2009

# Planetary boundaries

- climate change
- ocean acidification
- stratospheric ozone
- biogeochemical nitrogen (N) cycle and phosphorus (P) cycle
- global freshwater use
- land system change
- biological diversity loss
- chemical pollution
- Atmospheric aerosol loading

'*We estimate that humanity has already transgressed three planetary boundaries: for climate change, rate of biodiversity loss, and changes to the global nitrogen cycle. Planetary boundaries are interdependent, because transgressing one may both shift the position of other boundaries or cause them to be transgressed.*'



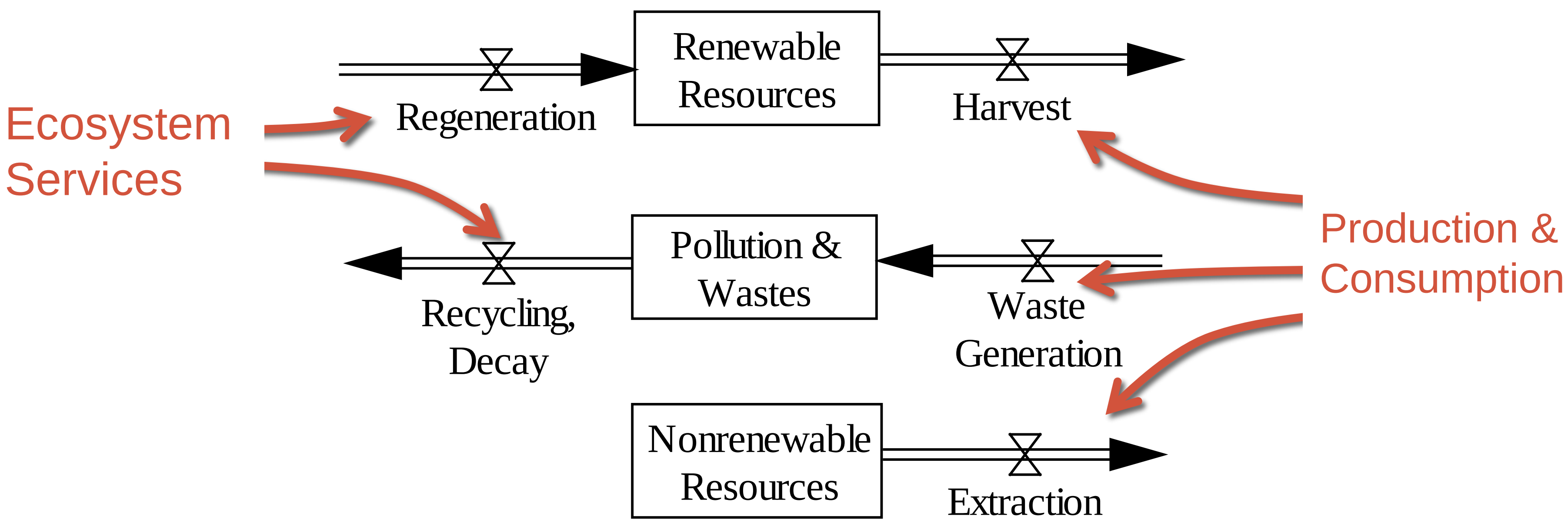

# Towards resilience

# Daly’s conditions for sustainability

1. Renewable resources cannot be used faster than they regenerate;
2. Pollution and wastes cannot be generated faster than they decay and are rendered harmless; and
3. Non-renewable resources cannot be consumed faster than they can be replaced by renewable substitutes (in the long run, they cannot be used at all).

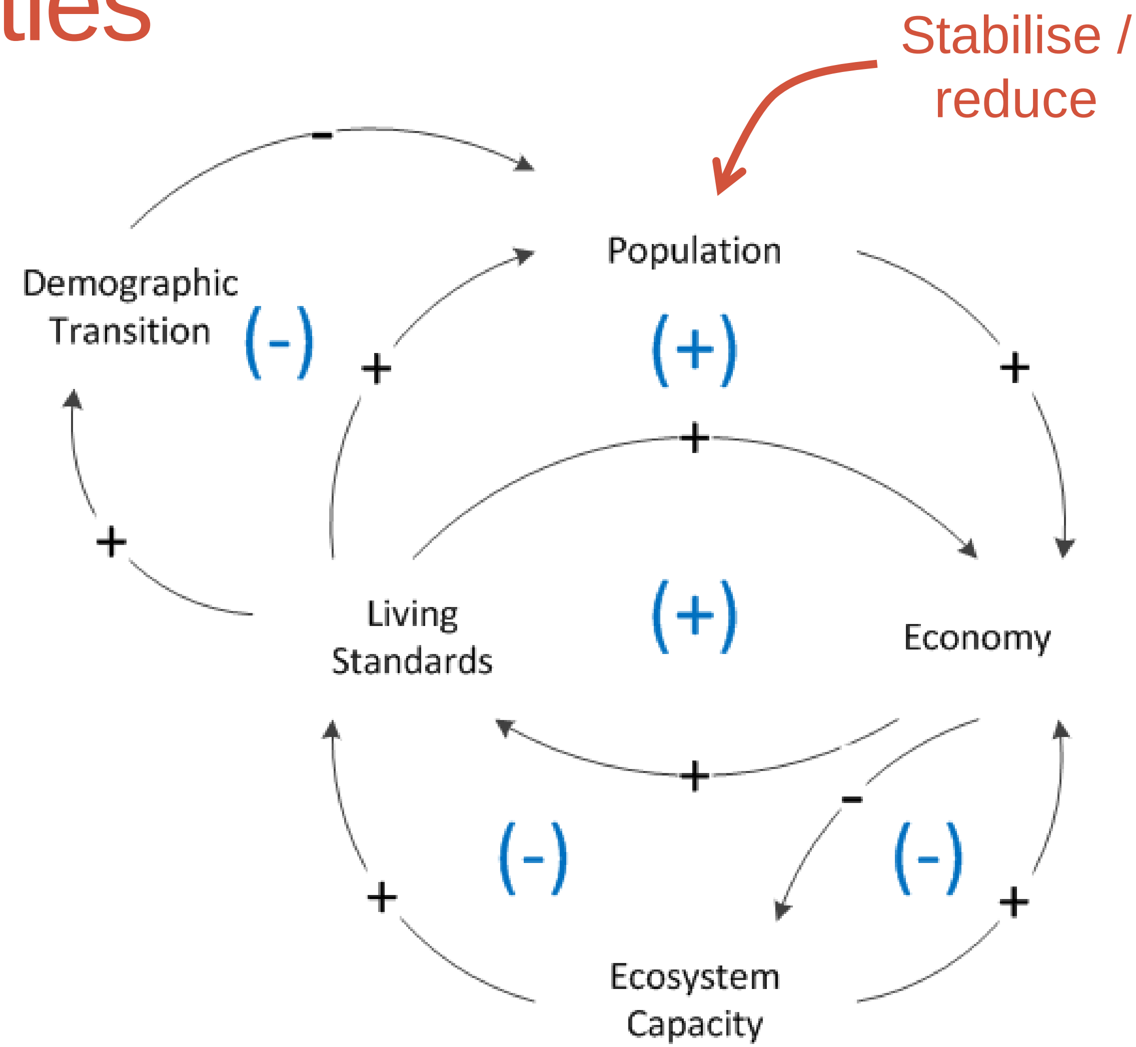
Source: Daly 1991

# In stock and flow terms ….




Source: Sterman 2011

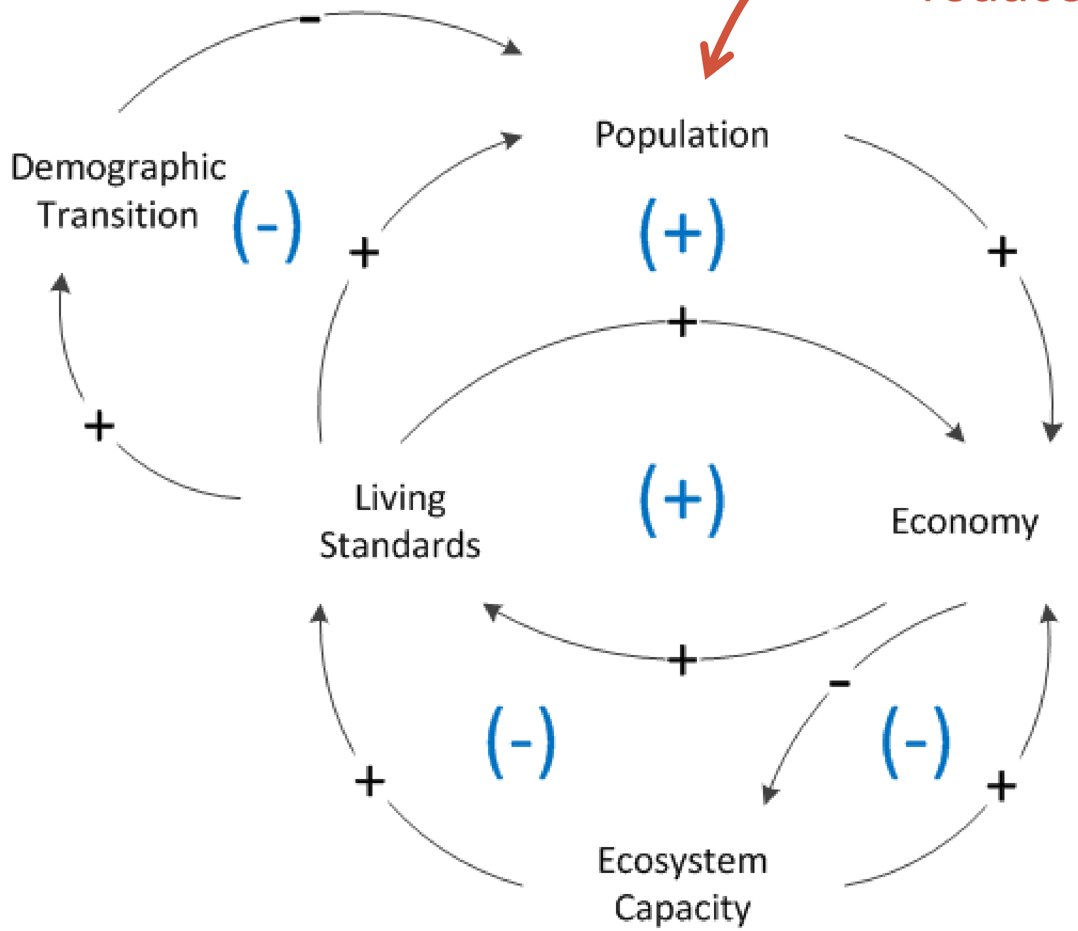
# Priorities



Stabilise /
reduce
Population
Demographic
Transition
(-)
(+)
Living
Standards
(+)
Economy
(-)
(-)
Ecosystem
Capacity

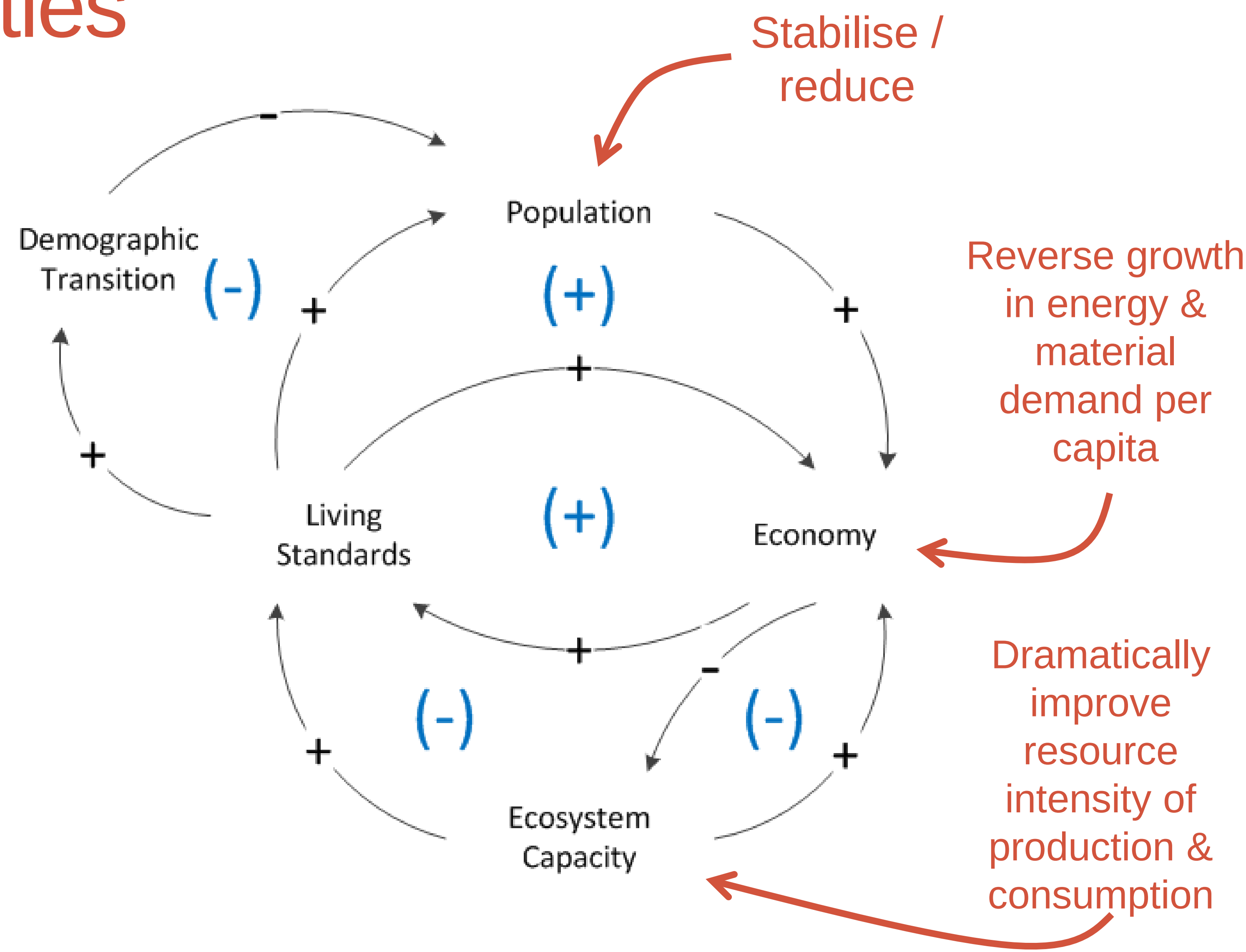
# Priorities

Stabilise / reduce




Reverse growth in energy & material demand per capita

# Priorities


Stabilise / reduce
Demographic Transition
Population
Reverse growth in energy & material demand per capita
Living Standards
Economy
Ecosystem Capacity
Dramatically improve resource intensity of production & consumption
(-)
(+)
(+)
(-)
(-)
+
-

GREAT ENGINEERING CHALLENGE

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Tuesday 7 August 2012

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ENGINEERS AUSTRALIA
Sydney Division

# And the challenge for engineers?

# Madly building for millenia

**10,000BC – industrial revolution**

- Settlements – basic infrastructure
- Agriculture

**Industrial revolution – now**

- Cities – water, power, communications
- Industrial production
- Resource extraction

# $21^{st}$ century

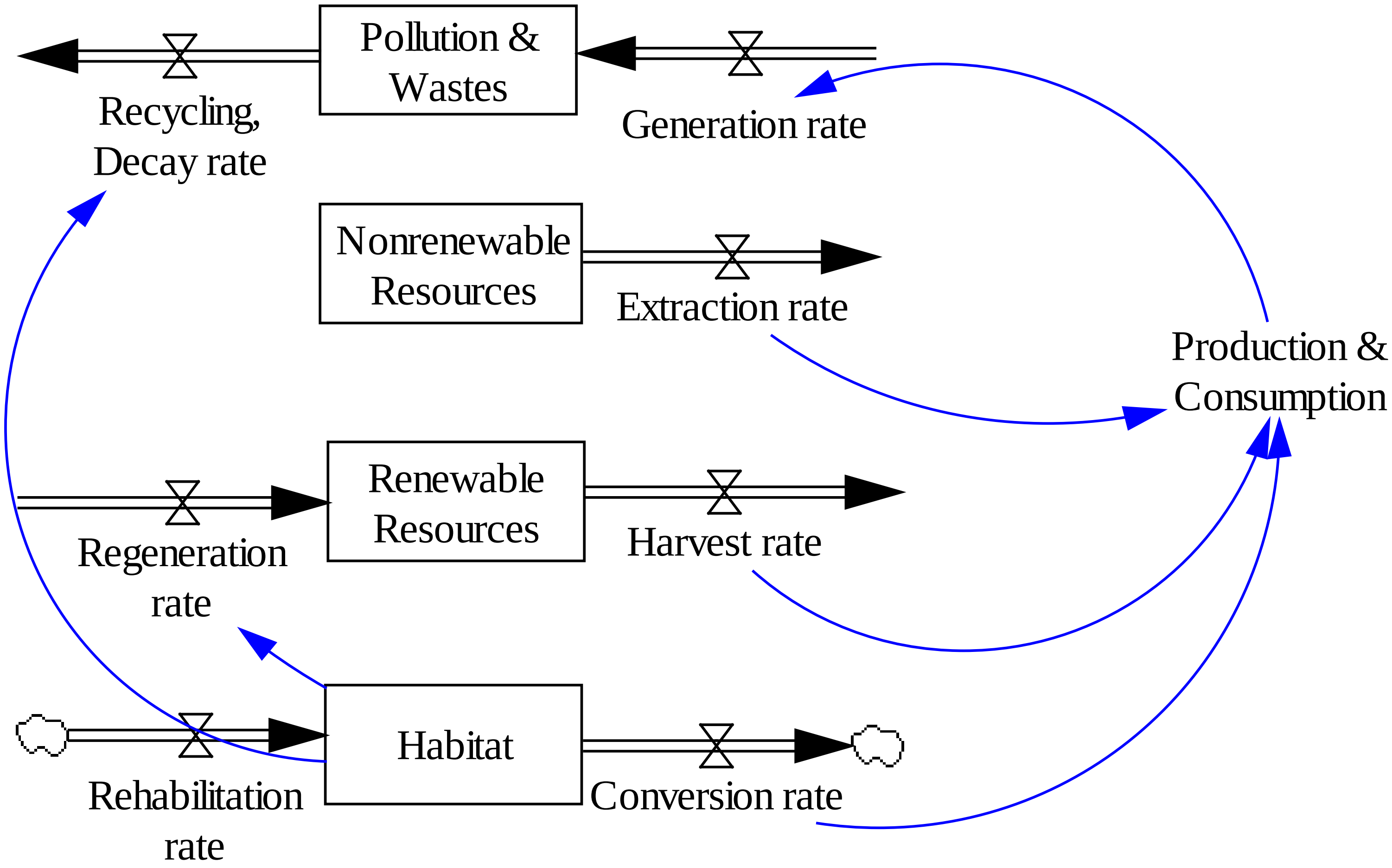
Given that:

- We are at or approaching limits
- Population is heading for 9-10 billion

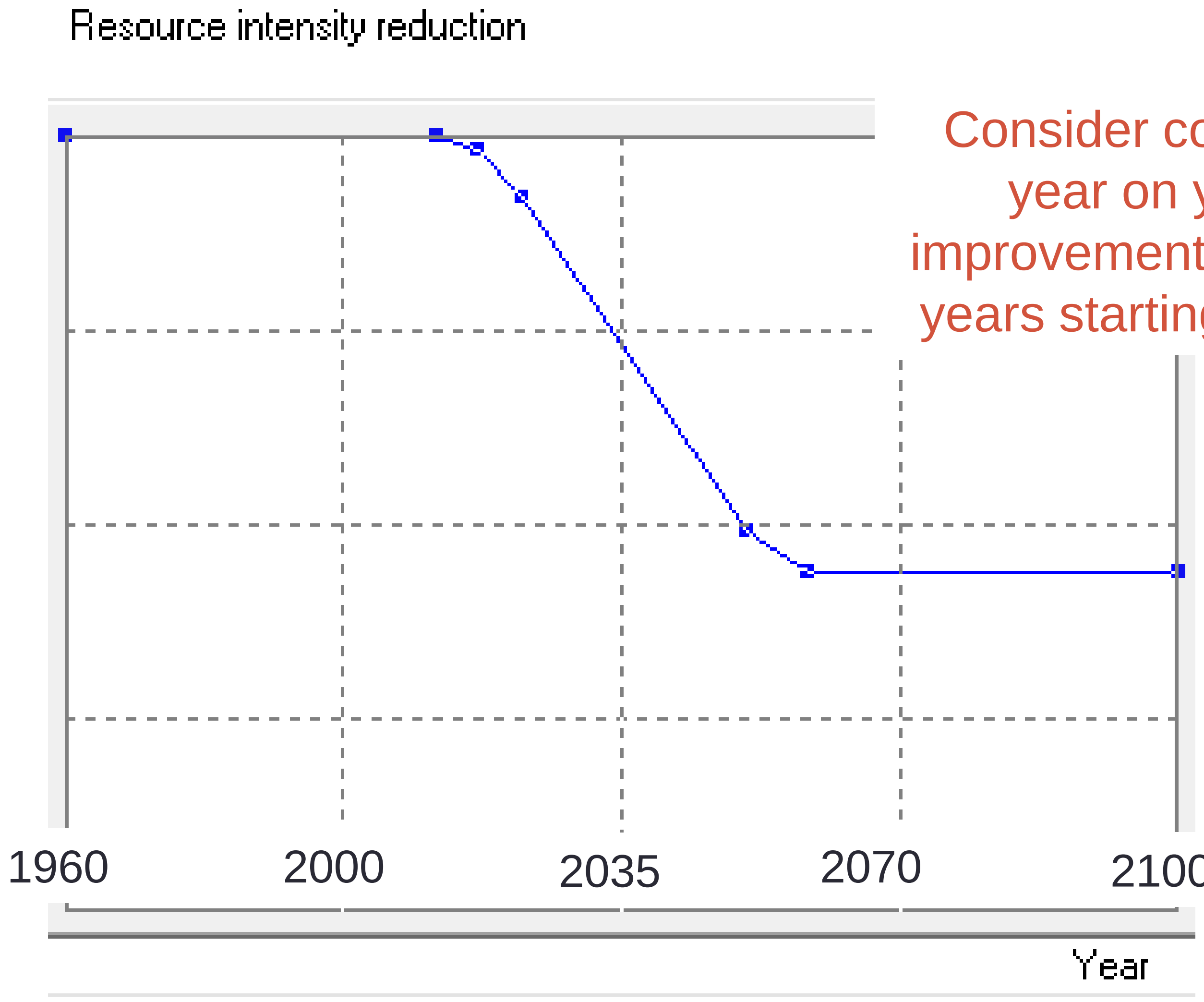
Engineers respond:

- Urgent improvements is resource efficiency
  - Less energy & materials per unit of GDP
  - Less pollution & waste per unit of energy / materials
  - Lower (to near zero) GHG emissions per unit of energy
  - Substitution of non-renewable resources / recycling

# Put this picture on your wall

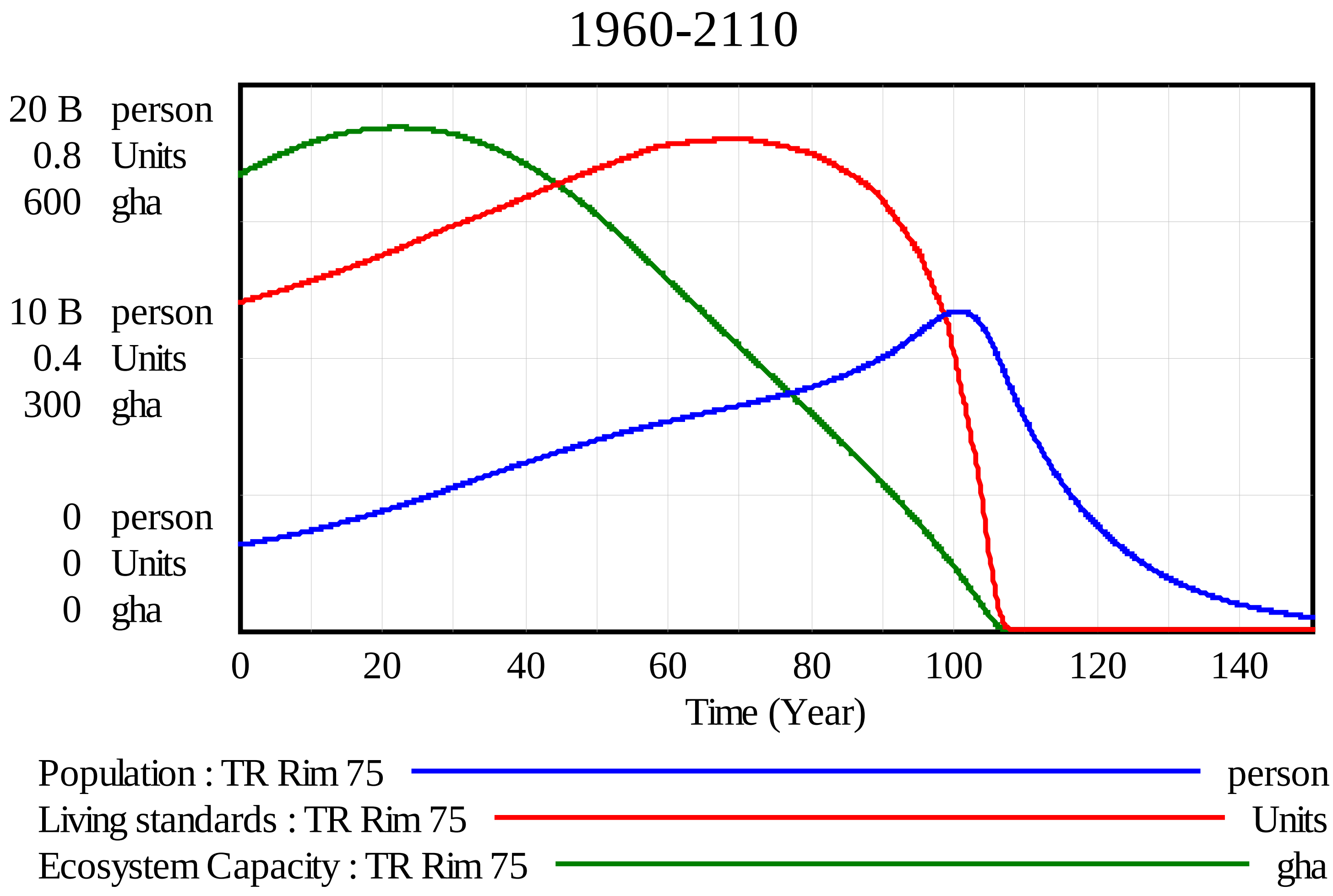


# How big is the challenge?

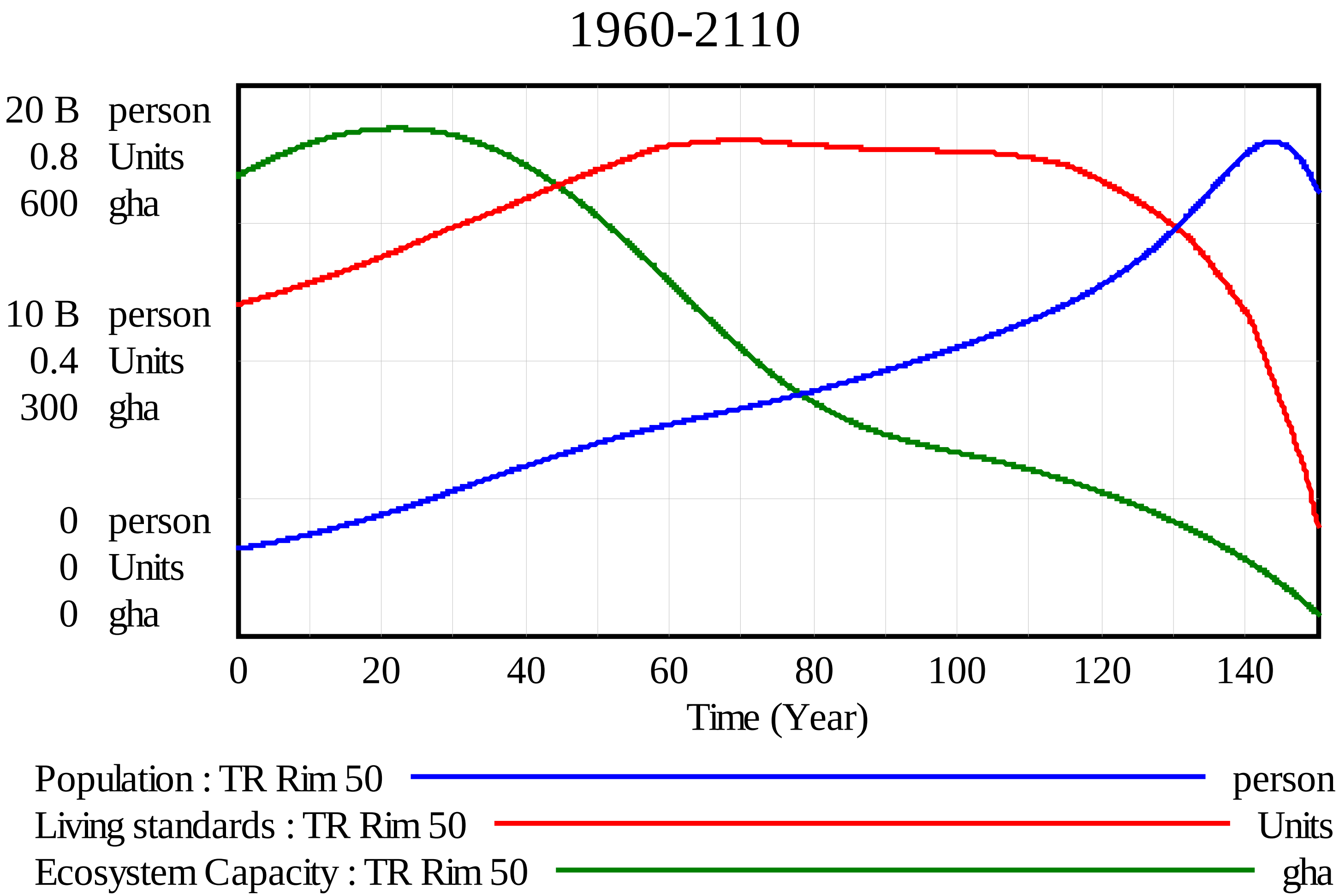



Consider constant year on year improvement over 50 years starting NOW!

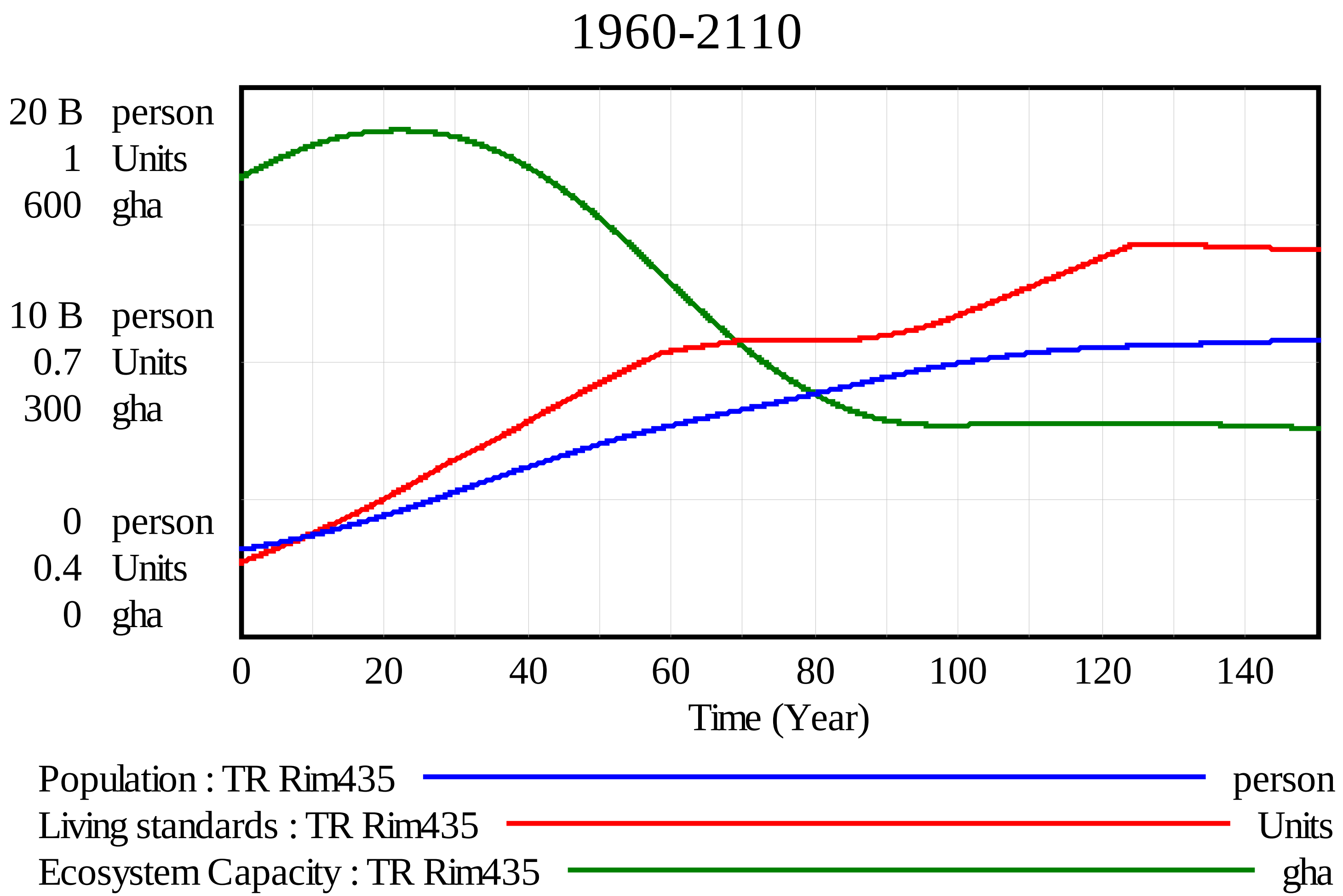
# 25% improvement



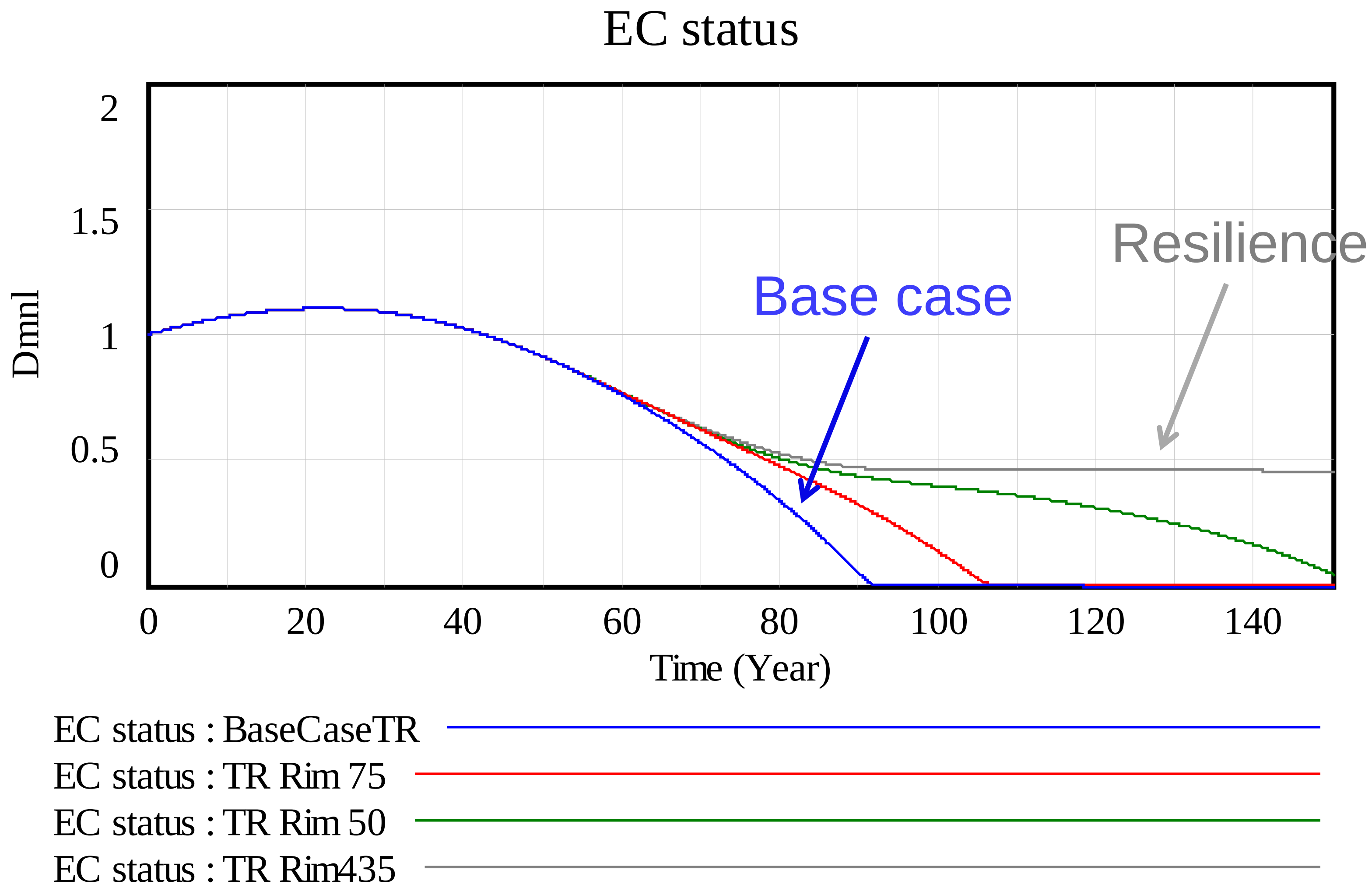
# 50% improvement



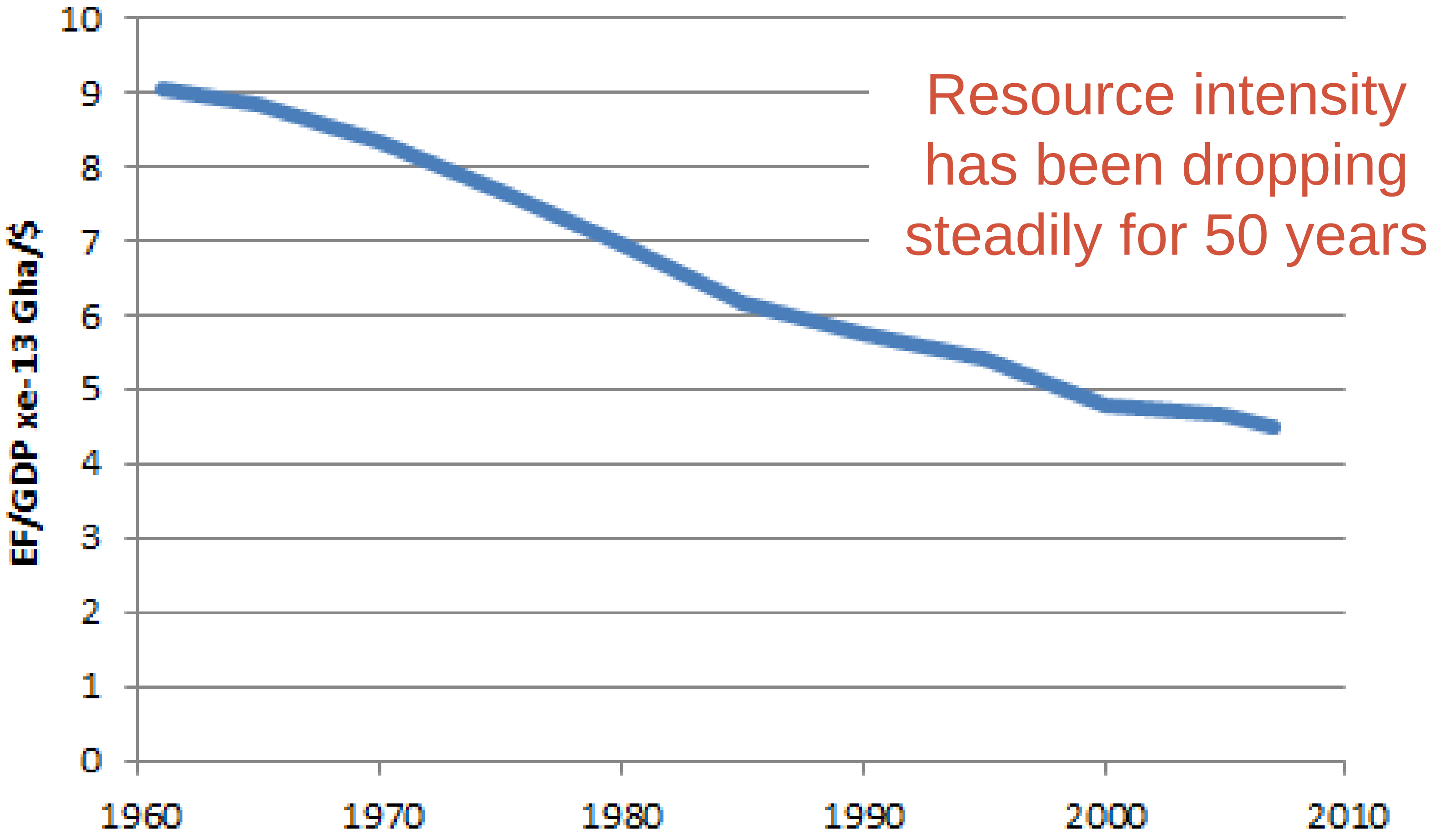
# 60% improvement



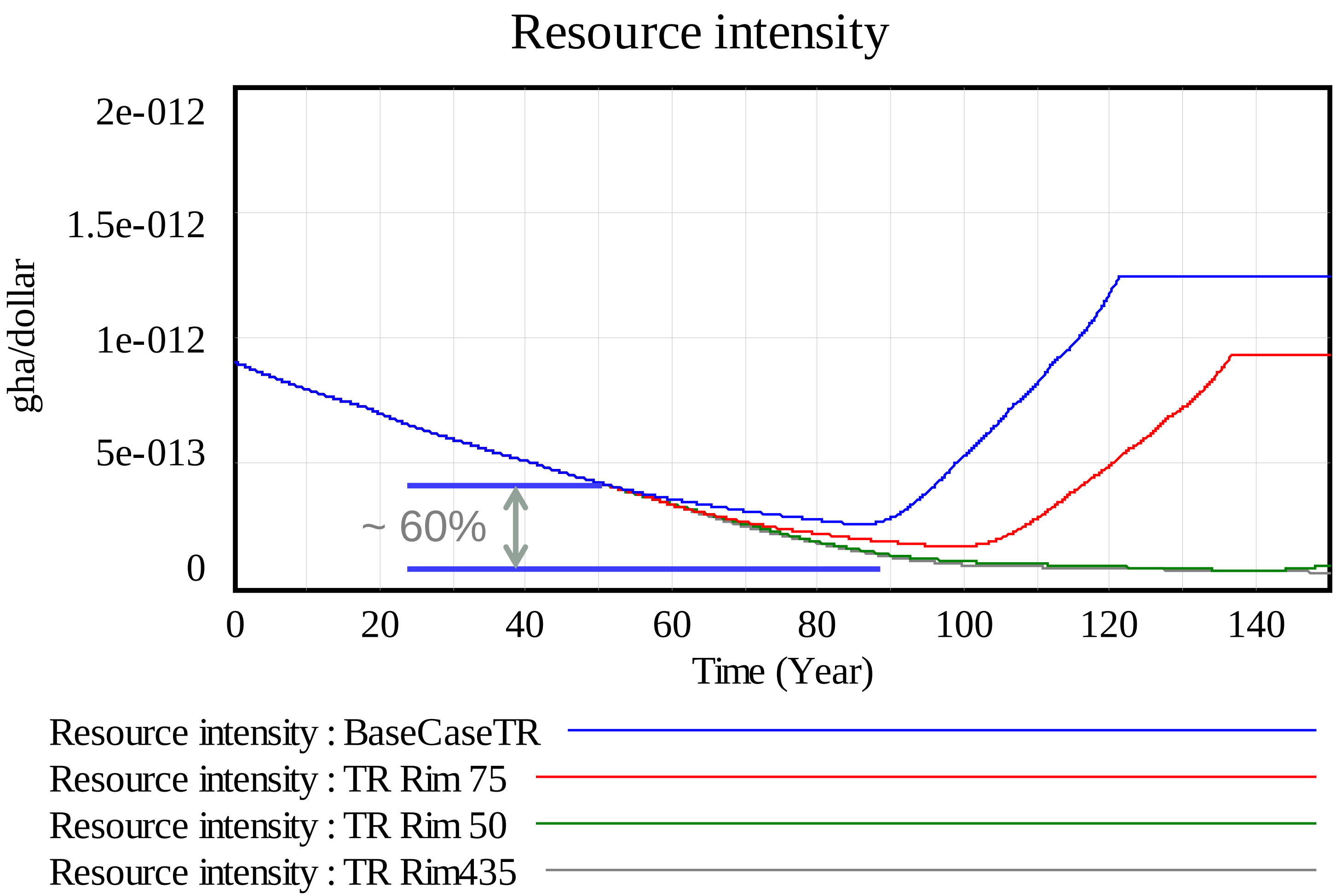
# Non linear behaviour



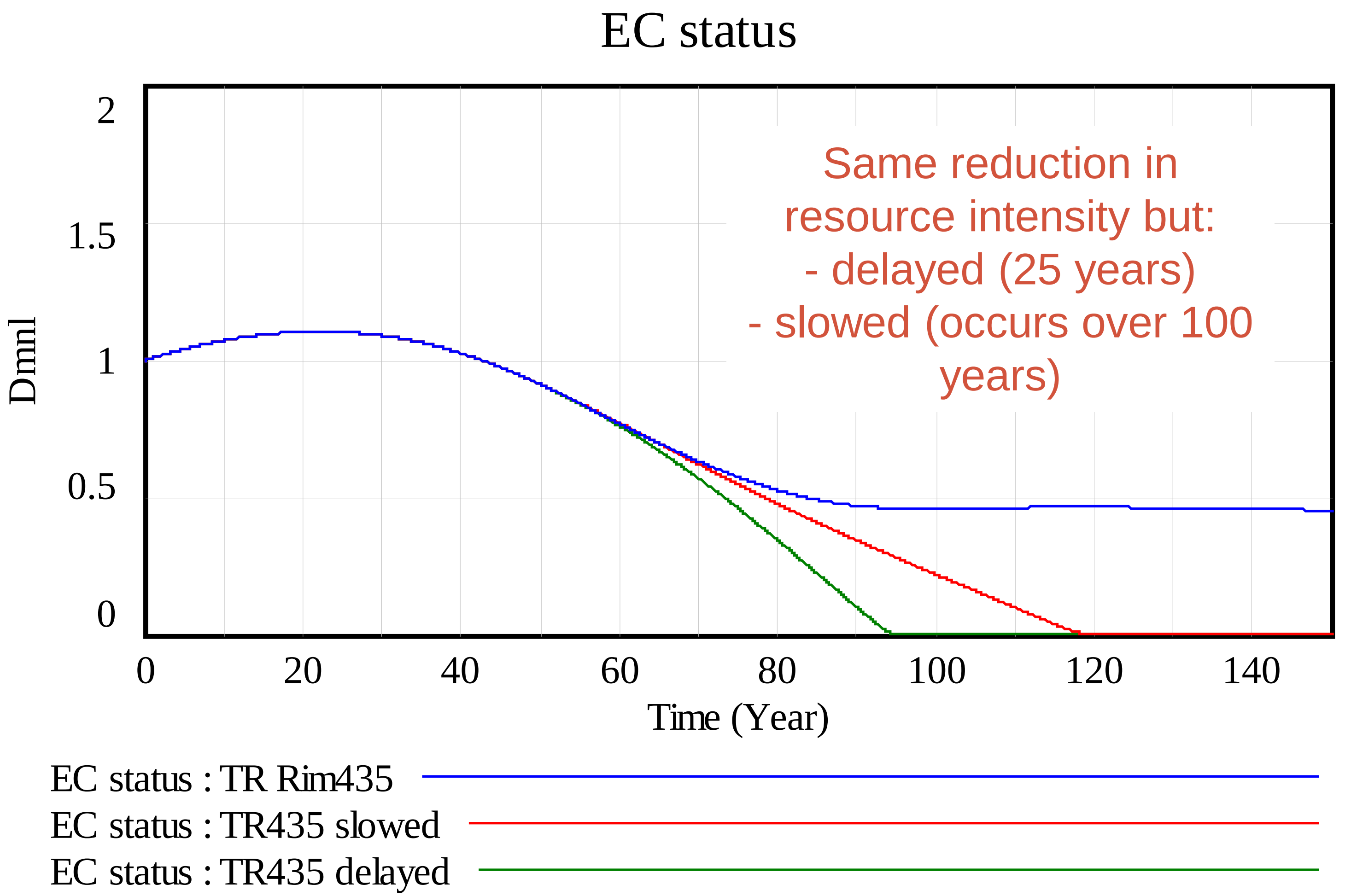
# How big is the challenge?



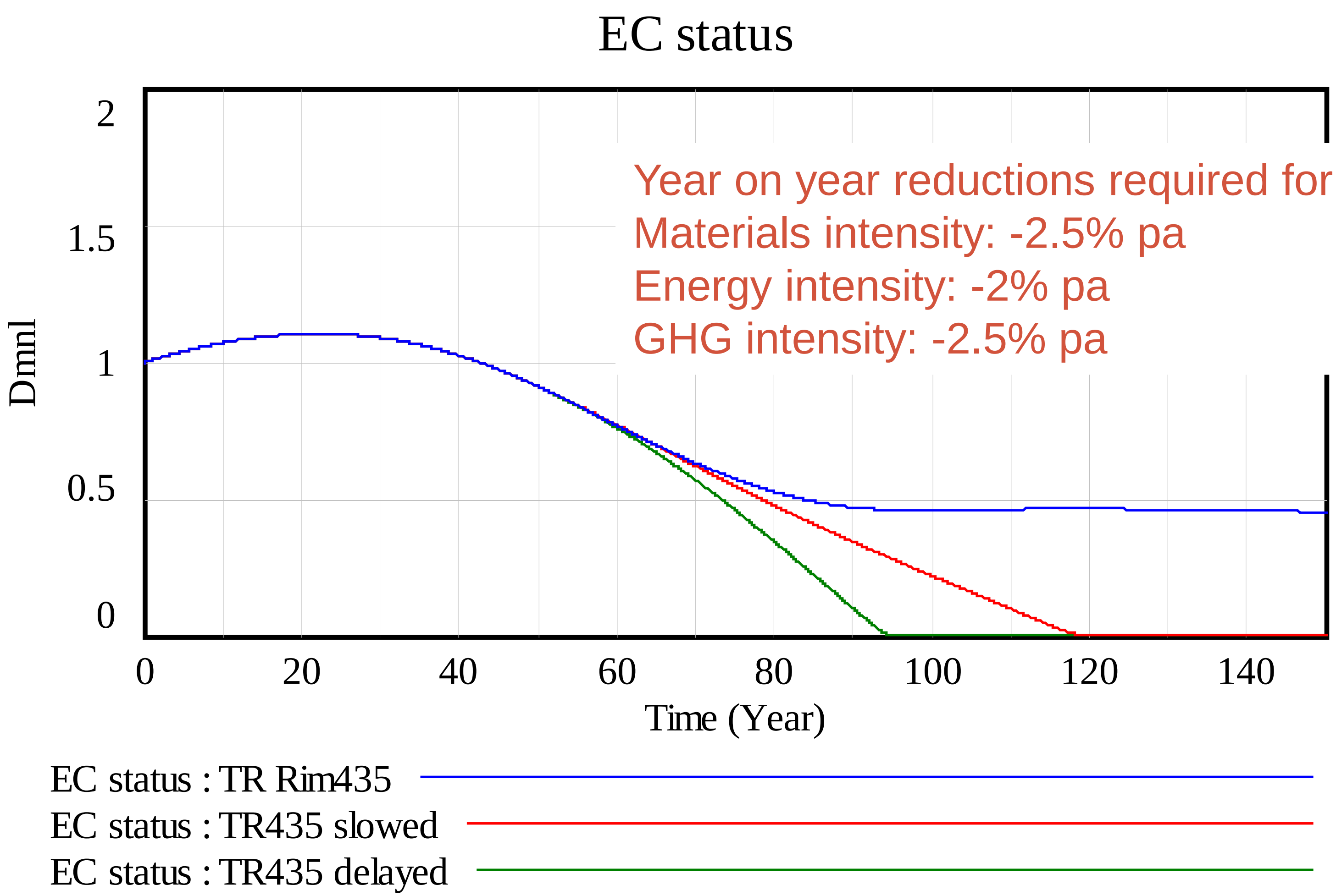
# Required to offset GDP growth



# This is urgent



# This is urgent




Year on year reductions required for 50 years
Materials intensity: -2.5% pa
Energy intensity: -2% pa
GHG intensity: -2.5% pa

# But remember

It’s not all engineering

- De-materialising the economy requires:
  - Less stuff required per unit GDP
  - Less energy & materials in the stuff

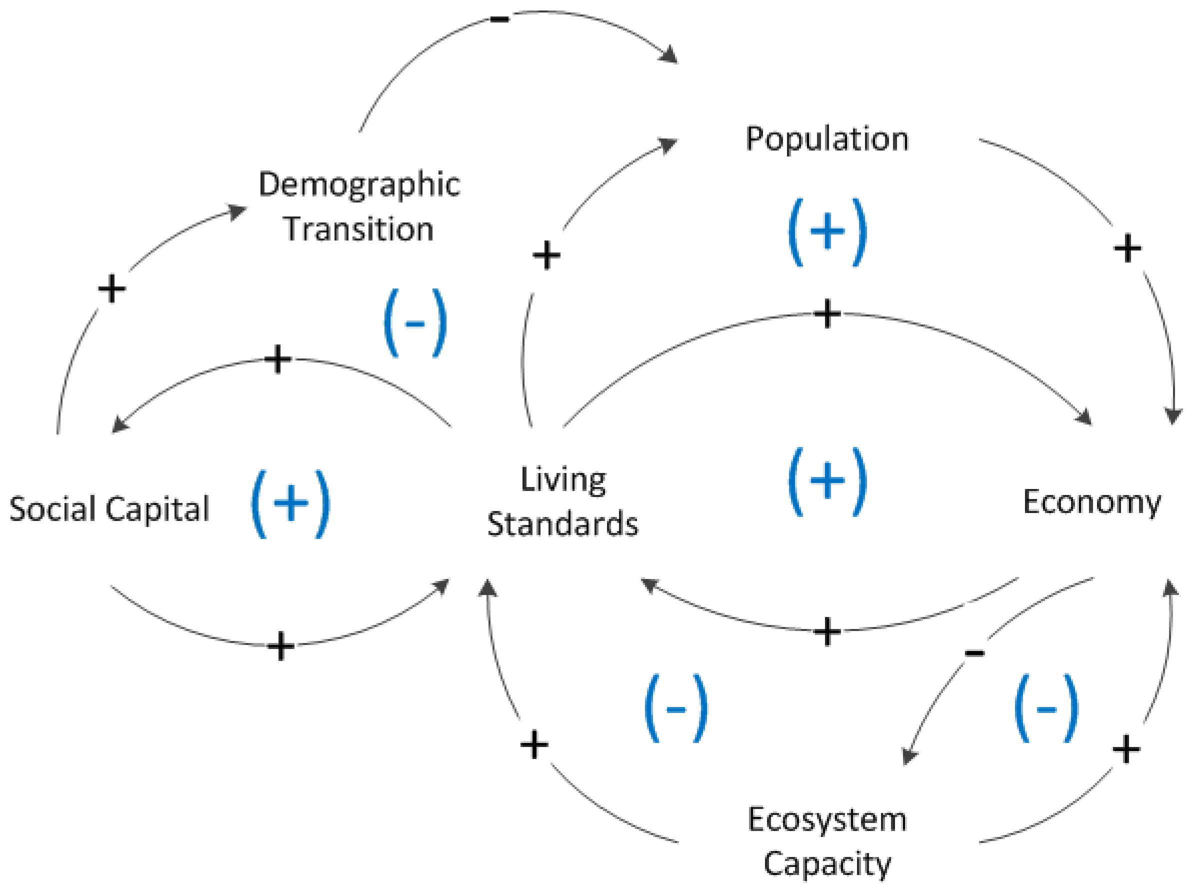
Exploiting diminishing resources requires:

- More energy and materials per unit of resource
- We are at that point for hydrocarbons and many minerals (including iron ore).

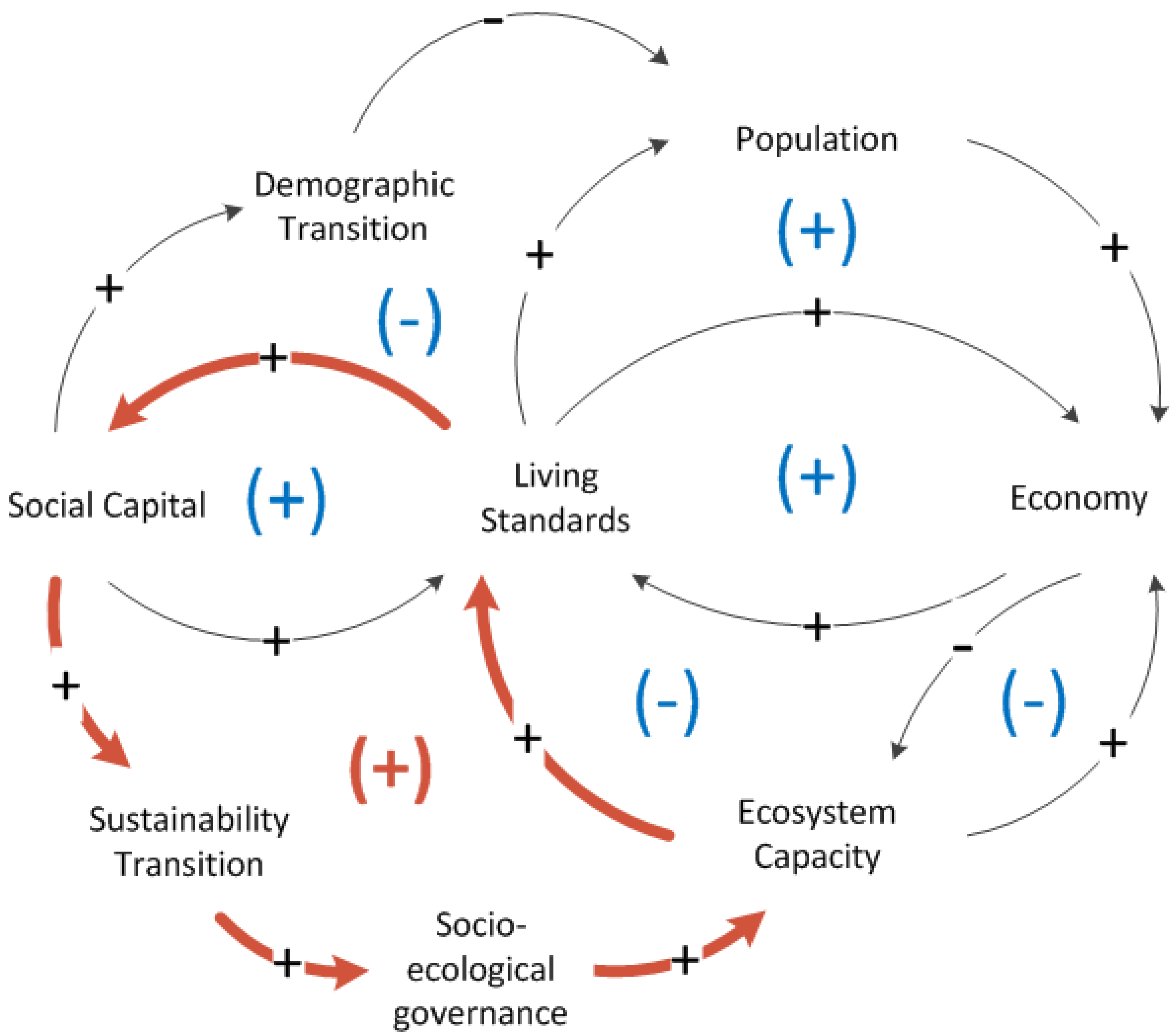
- There are many “limits” missing from this model

# Can engineers solve this alone?

# Strengthening Social Capital



# Insert new feedback loop here!



How much of this …

Has turned into this ….


… during this talk?

# Can engineers really *make it happen*?