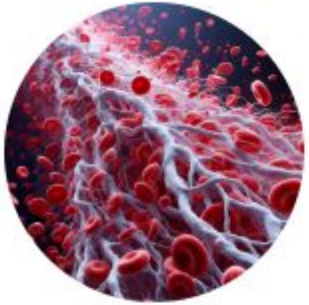


7AM

12PM in London (GMT), 9PM in Tokyo (GMT+9)

Theoretical Biology and History of Biology

Moderator: Yashvardhan Jain, *Indiana University*

Presenter: Manfred Laubichler, *Arizona State University*

Manfred Laubichler, ***Arizona State University and Santa Fe Institute***

ASU School of Complex Adaptive Systems
Arizona State University

On the Dynamics of the Anthropocene

Manfred D. Laubichler

MAX PLANCK INSTITUTE OF GEOANTHROPOLOGY
SANTA FE INSTITUTE
COMPLEXITY SCIENCE HUB VIENNA
Global Climate Forum

THE ANGEL OF HISTORY

Angelus Novus, Paul Klee

This storm irresistibly propels him into the future to which his back is turned, while the pile of debris before him grows skyward. This storm is what we call progress.

-Walter Benjamin

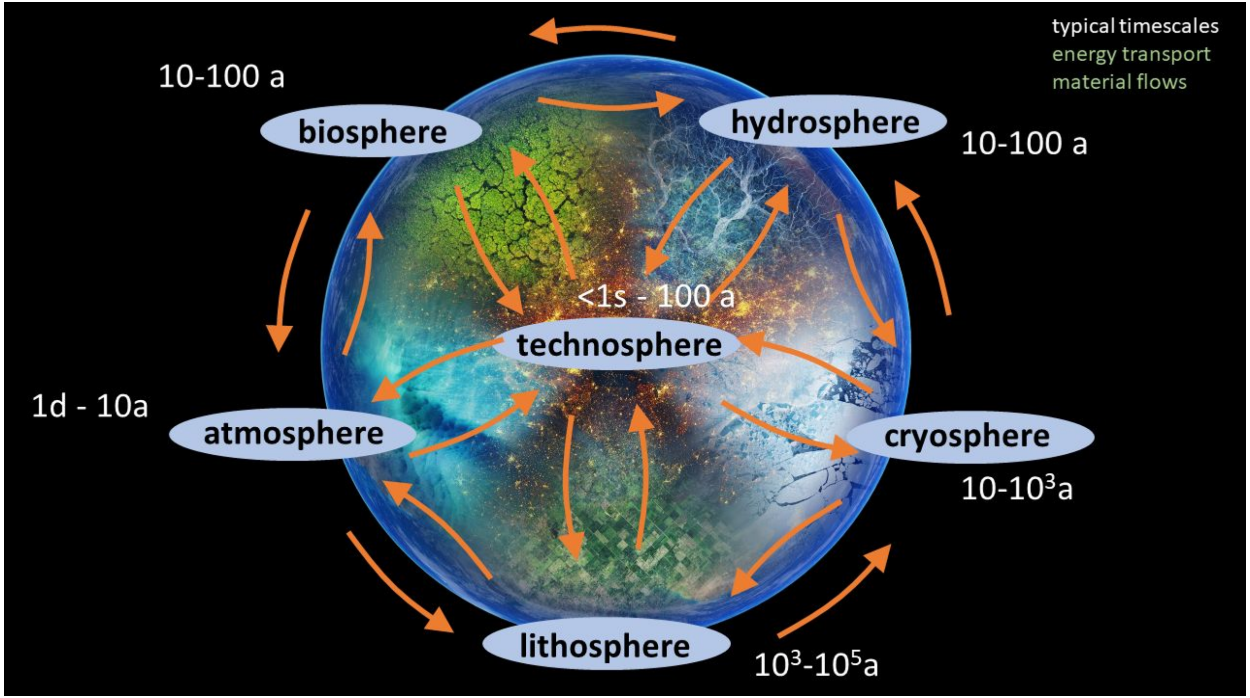
The Challenge

- We have entered the Anthropocene— a consequence of complex and long co-evolutionary dynamics!
- We are shaping and engineering our planet at global scales
- Humankind is no longer in a safe operating space
- New Global Challenges emerge at rapid pace that contribute to *systemic risks and systems' failures*
- **A new scientific understanding is needed to meet these challenges**

The deep history of evolved complexity — a story of major transitions

- The origin of life, cellular life, multicellular life, etc.
- Major interconnected transitions in:
  - Organization, including social organization
  - Energy systems
  - Knowledge and information flows
  - Material Flows
- Emerging layers of complexity and feedbacks
- The Technosphere is such a major transition in evolution

The Technosphere as a major transition in evolution



Laubichler, Renn, Winkelmann, Roberts, Schlosser, in preparation

Standard Evolutionary Theory is insufficient

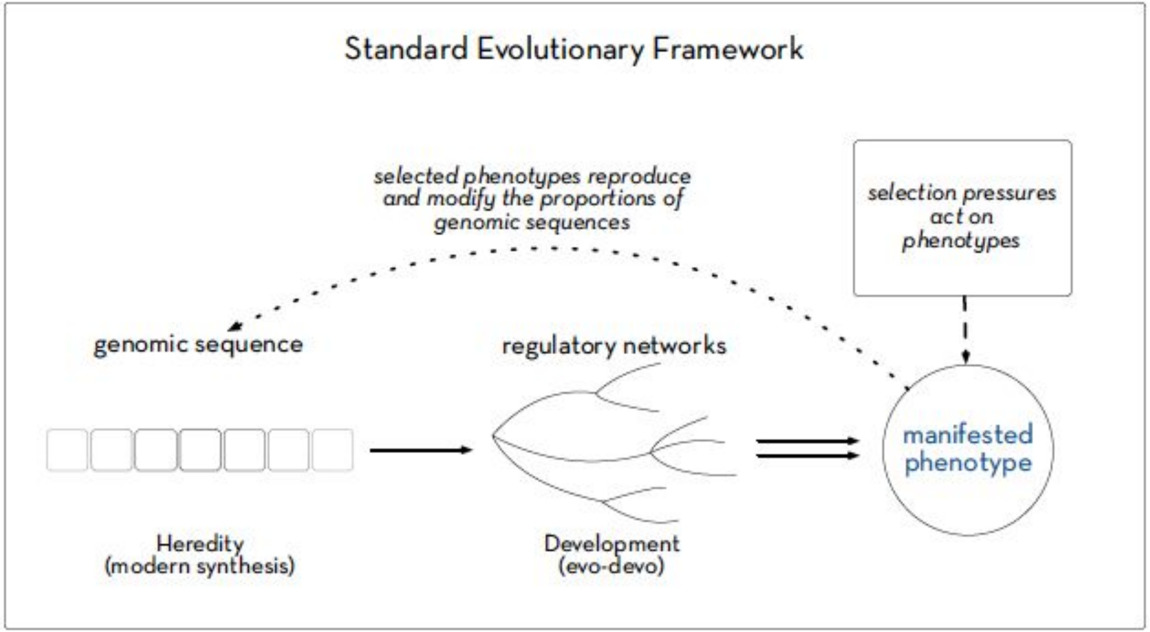
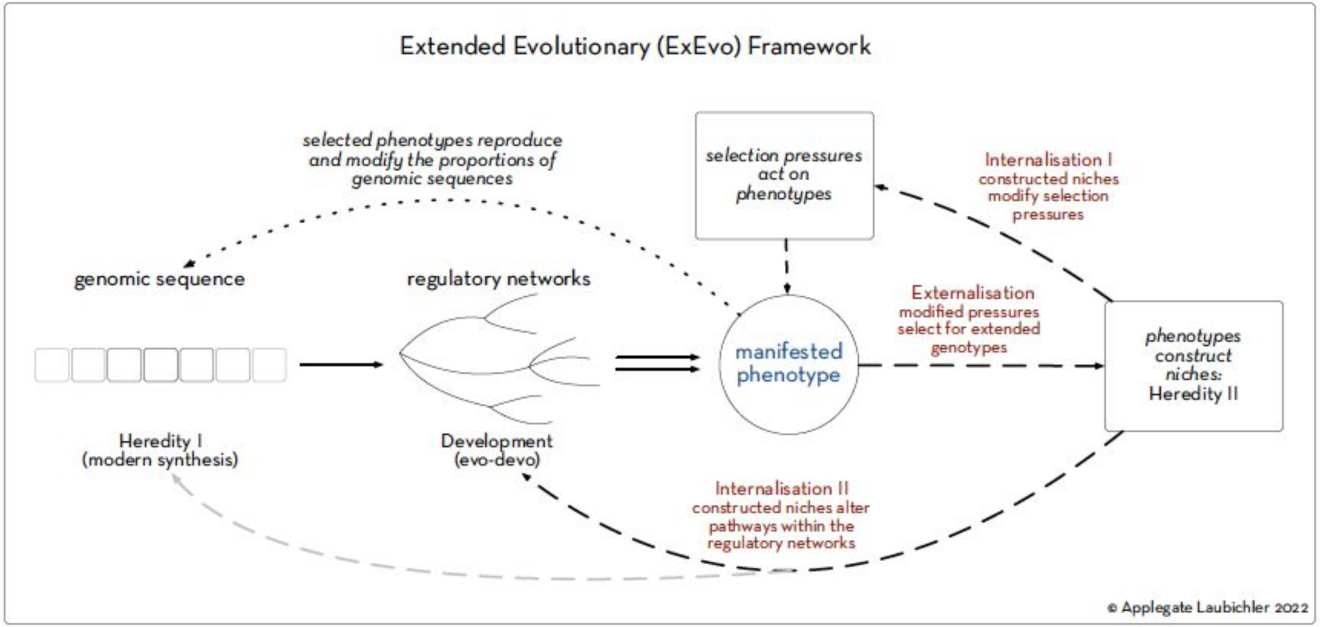


Figure 1: The Standard Evolutionary Framework.

Standard Evolutionary Theory is insufficient

- Selection as the main effective feedback mechanism
- Explanations of the origin of variation outsourced to physics
- Evolutionary dynamics as a temporal sequence of allele frequencies
- Implicit assumption of optimization
- ODEs as the mathematical structure with a strong preference towards equilibrium dynamics

Extended Evolutionary Theory



Laubichler and Renn, 2015

Extended Evolutionary Dynamics

Over evolutionary time scales the interaction between systems and their niches exhibits two types of simultaneous dynamics:

Externalization: Actions of the system construct the niche and stable aspects of the constructed niche then act as regulatory elements contributing to the control of the system’s behavior

Internalization: Elements of the niche that have the potential to regulate system behavior are incorporated into the regulatory network in a stable way (often replacing previous internal elements)

Extended Evolution

- Emphasis on complex systems transformations and multiple feedback mechanisms
- Developmental mechanisms explain the origin of variation
- Evolutionary history not time
- Path-dependency and construction
- Mathematical structure more complex focused on stochastic processes and non-equilibrium dynamics

Mathematically integrating development, heredity and population dynamics

Developmental (fine) Time Scale: k=1,...,K developmental time points

Latent states

$$\mathbf{x}^t_{d,k} = f(\mathbf{x}^t_{d,k-1}, \mathbf{w}^t_{d,k})$$

Possibly nonlinear state transition function

Process noise term

Noisy measurements

$$\mathbf{y}^t_{d,k} = d(\mathbf{x}^t_{d,k}, \mathbf{v}^t_{d,k})$$

Possibly nonlinear measurement function

Measurement noise term

Noise parameters $\boldsymbol{\theta}^t_{d,k} \sim \nu(\boldsymbol{\theta}^t_{d,k-1}, \boldsymbol{\theta}^t_{d,k})$

Transition kernel

Developmental Trajectory for **d**-th individual in generation **t** $\mathbf{X}^t_{d,(K)} = \{\mathbf{x}^t_{1,d}, \mathbf{x}^t_{2,d}, .., \mathbf{x}^t_{K,d}\}$

Mathematically integrating development, heredity and population dynamics

The developmental trajectory becomes the input for next time scale

$$\mathbf{X}^t_{d,(K)} = \{\mathbf{x}^t_{1,d}, \mathbf{x}^t_{2,d}, .., \mathbf{x}^t_{K,d}\}$$

Intergenerational (coarse) Time Scale: t=1,...,T Generations

Latent states $\tilde{\mathbf{X}}^{(K)}_{d,t} = g(\tilde{\mathbf{X}}^{(K)}_{d,t-1}, \mathbf{X}^t_{d,(K)}, \hat{\mathbf{w}}_{d,t})$

Possibly nonlinear transition function
(also encodes a time-varying network describing interactions between individuals in a population)

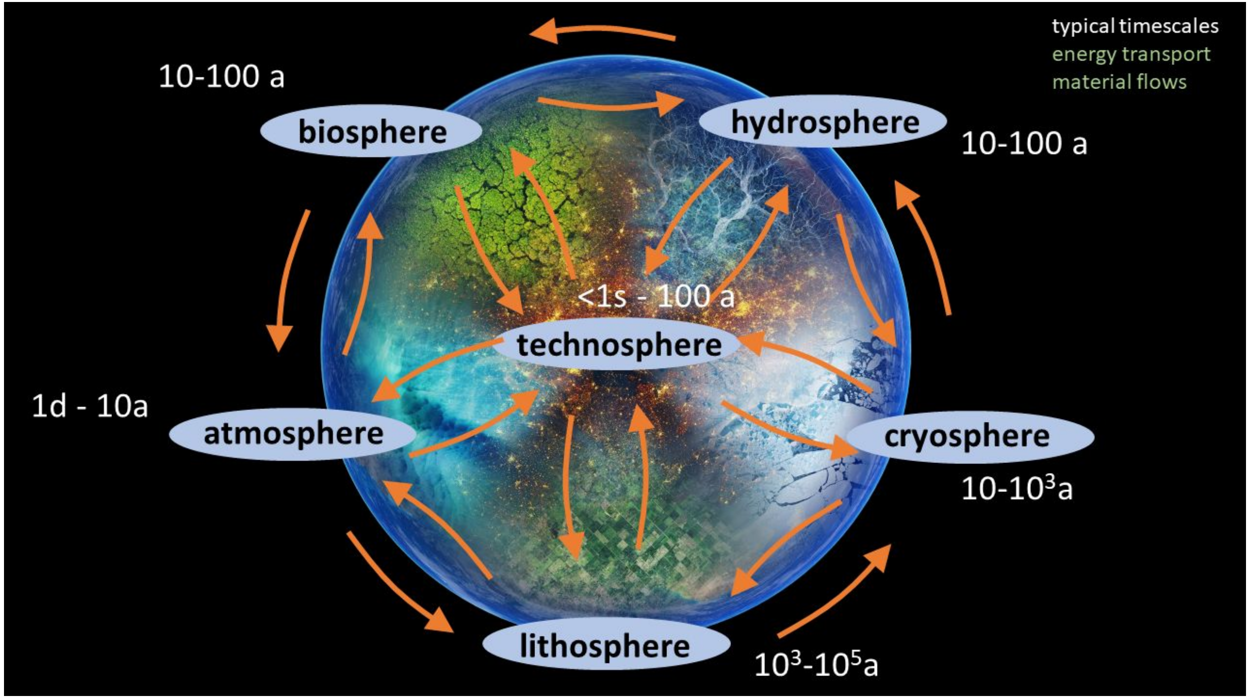
Coarse time scale noise parameters $\Lambda^{(K)}_{d,t} \sim \eta(\Lambda^{(K)}_{d,t}, \Lambda^{(K)}_{d,t+1})$

Measurements $\mathbf{Y}^{(K)}_{d,t} = b(\tilde{\mathbf{X}}^{(K)}_{d,t}, \hat{\mathbf{v}}_{d,t})$

Possibly nonlinear measurement function

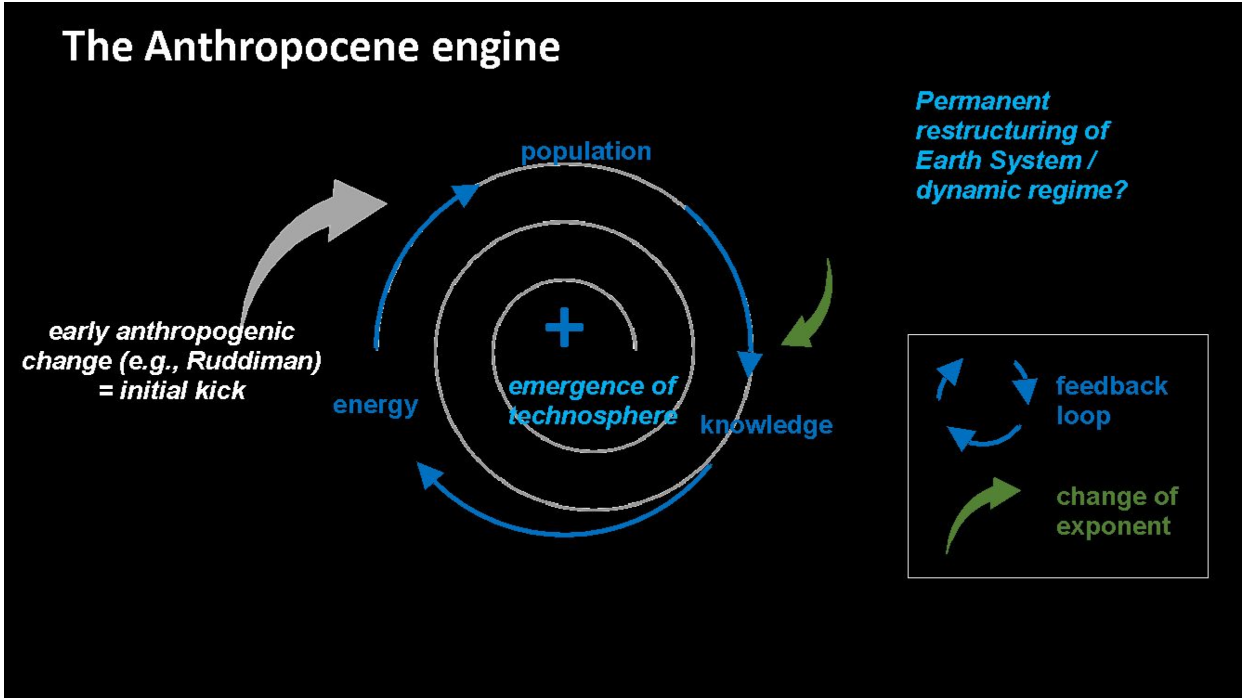
*Cool note: setting **k=1**, iterate over **t**, can recover population genetics models; setting **t=1**, iterate over **k**, can recover models of development/GRNs

The Technosphere as a major transition in evolution



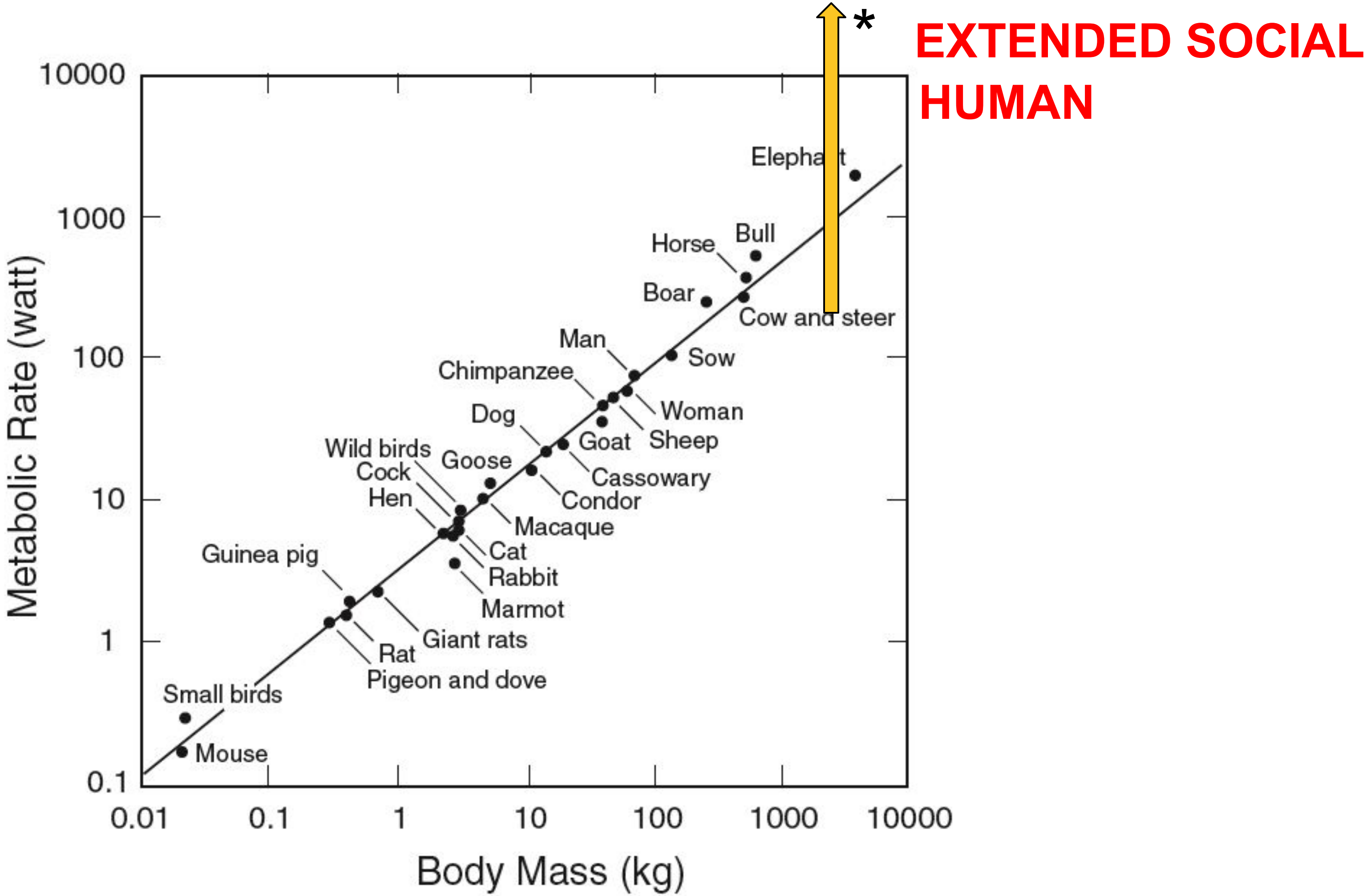
Laubichler, Renn, Winkelmann, Roberts, Schlosser, in preparation

The dynamics of the Anthropocene

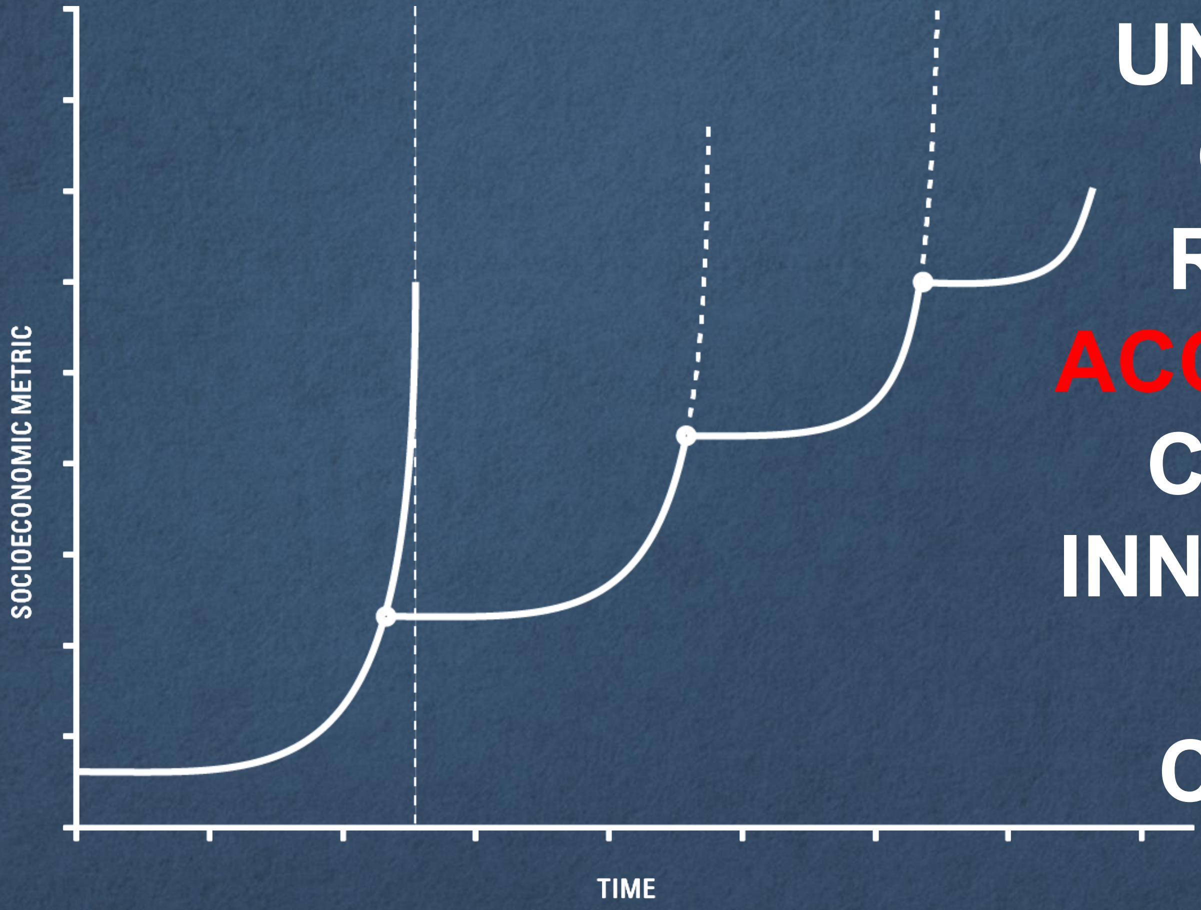


Our “natural” metabolic rate *~90 watts*

Our social metabolic rate *~11,000 watts*



EXTENDED SOCIAL HUMAN
*
Metabolic Rate (watt)
Body Mass (kg)
10000
1000
100
10
1
0.1
0.01
0.1
1
10
100
1000
10000
Elephant
Bull
Horse
Boar
Cow and steer
Sow
Man
Chimpanzee
Woman
Sheep
Goat
Dog
Cassowary
Condor
Goose
Wild birds
Cock
Hen
Macaque
Cat
Rabbit
Marmot
Guinea pig
Giant rats
Rat
Pigeon and dove
Small birds
Mouse

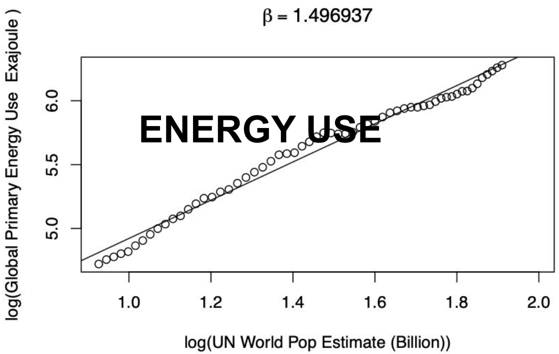


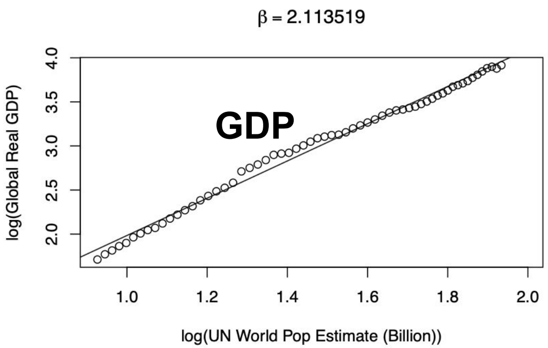
UNBOUNDED GROWTH REQUIRES ACCELERATING CYCLES OF INNOVATION TO AVOID COLLAPSE

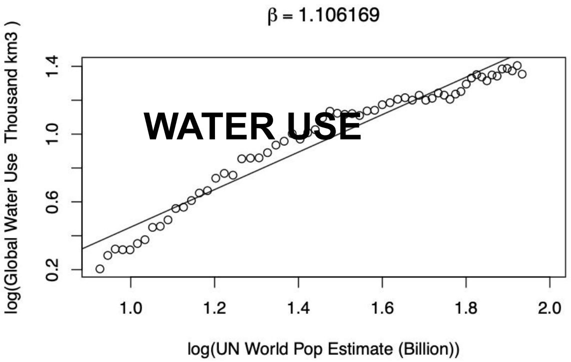
The Question

CAN WE EXTEND THIS FRAMEWORK TO THE SOCIO-ECONOMIC DYNAMIC AND EVOLUTION OF THE ENTIRE PLANET CONSIDERED AS AN INTEGRATED, NETWORKED COMPLEX ADAPTIVE SYSTEM (THE ANTHROPOCENE)?

D. Painter, M. Laubichler, C.P. Kempes & G.B. West; work in progress


β = 1.496937
ENERGY USE
log(Global Primary Energy Use Exajoule)
log(UN World Pop Estimate (Billion))


β = 2.113519
GDP
log(Global Real GDP)
log(UN World Pop Estimate (Billion))

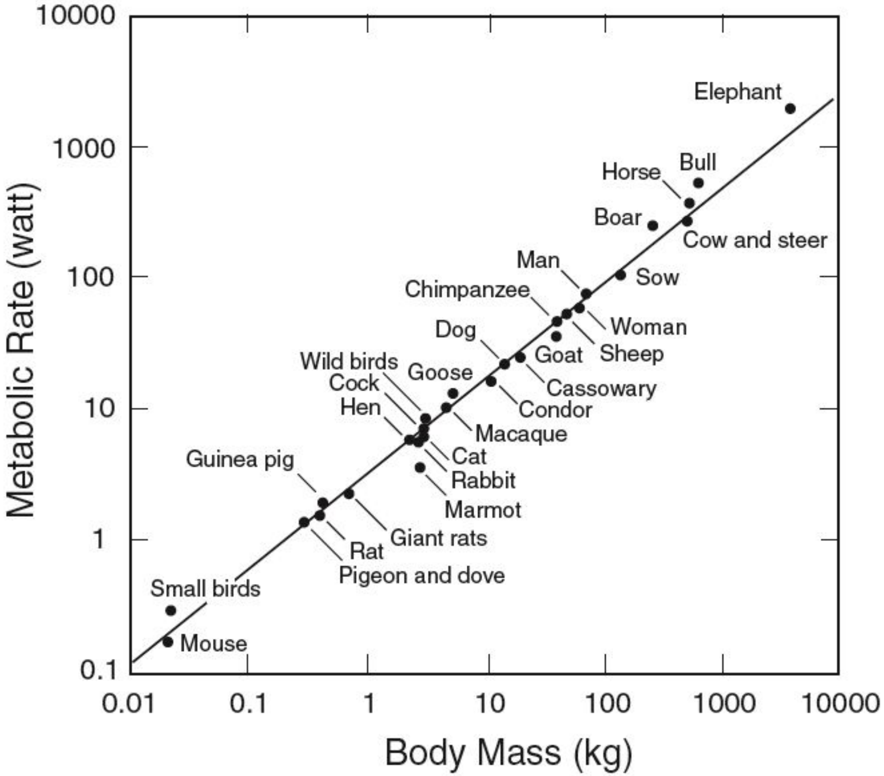

β = 1.106169
WATER USE
log(Global Water Use Thousand km3)
log(UN World Pop Estimate (Billion))

Biological Scaling

BIOLOGICAL METABOLIC RATE (*B*)

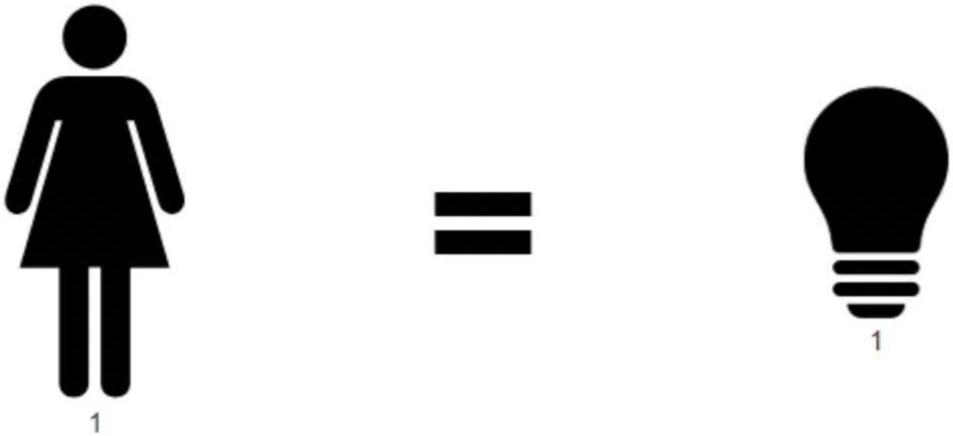
THIS IS THE RATE AT WHICH ENERGY NEEDS TO BE SUPPLIED TO AN ORGANISM IN ORDER TO:

- *MAINTAIN ITS PRESENT INACTIVE STATE (BASAL METABOLIC RATE)*



Metabolic Rate (watt)
10000
1000
100
10
1
0.1
Body Mass (kg)
0.01
0.1
1
10
100
1000
10000
Elephant
Bull
Horse
Boar
Cow and steer
Man
Sow
Chimpanzee
Woman
Sheep
Dog
Goat
Cassowary
Condor
Wild birds
Cock
Hen
Goose
Macaque
Cat
Rabbit
Marmot
Guinea pig
Giant rats
Rat
Pigeon and dove
Small birds
Mouse

100 Watts or 2000 calories a day



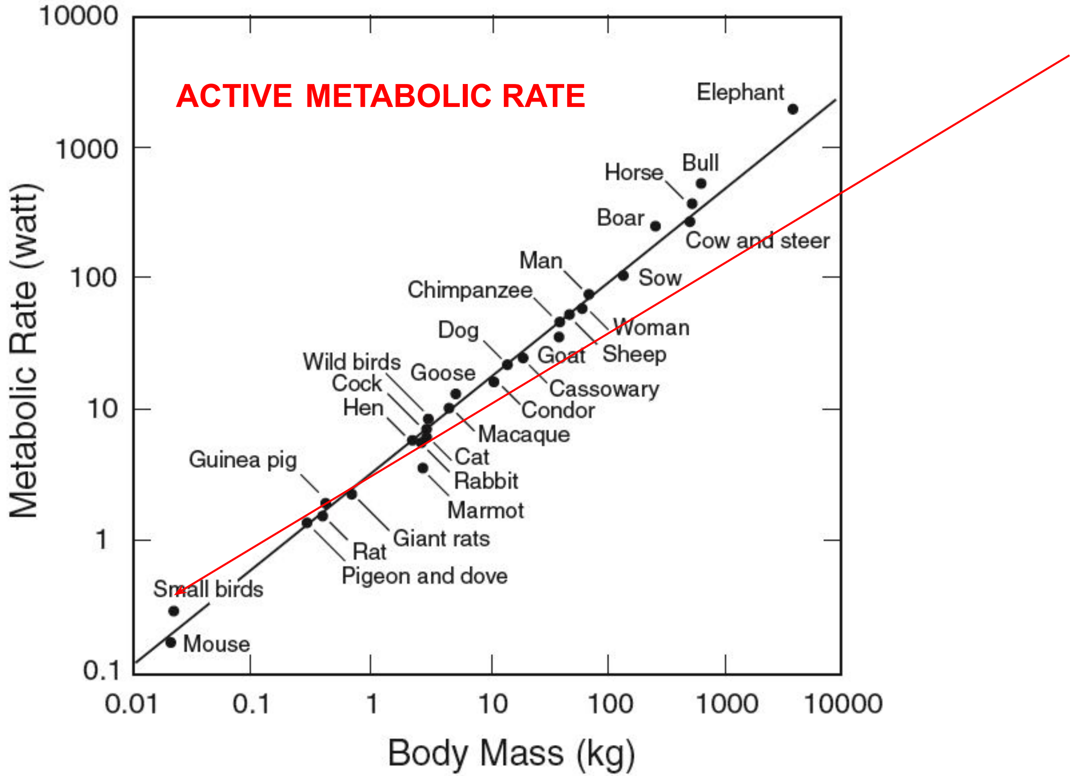
BIOLOGICAL METABOLIC RATE (*B*)

THIS IS THE RATE AT WHICH ENERGY NEEDS TO BE SUPPLIED TO AN ORGANISM IN ORDER TO:

- ***MAINTAIN ITS PRESENT INACTIVE STATE (BASAL METABOLIC RATE)***

ACTIVE METABOLIC RATE IS APPROXIMATELY 2-3 TIMES BASAL METABOLIC RATE WITH APPROXIMATELY THE SAME EXPONENT

THIS WAS TRUE FOR HUMAN BEINGS IN OUR "NATURAL" STATE


ACTIVE METABOLIC RATE
Metabolic Rate (watt)
10000
1000
100
10
1
0.1
0.01
0.1
1
10
100
1000
10000
Body Mass (kg)
Elephant
Horse
Bull
Boar
Cow and steer
Man
Sow
Chimpanzee
Woman
Dog
Goat
Sheep
Wild birds
Goose
Cock
Cassowary
Hen
Condor
Macaque
Cat
Rabbit
Guinea pig
Marmot
Giant rats
Rat
Pigeon and dove
Small birds
Mouse

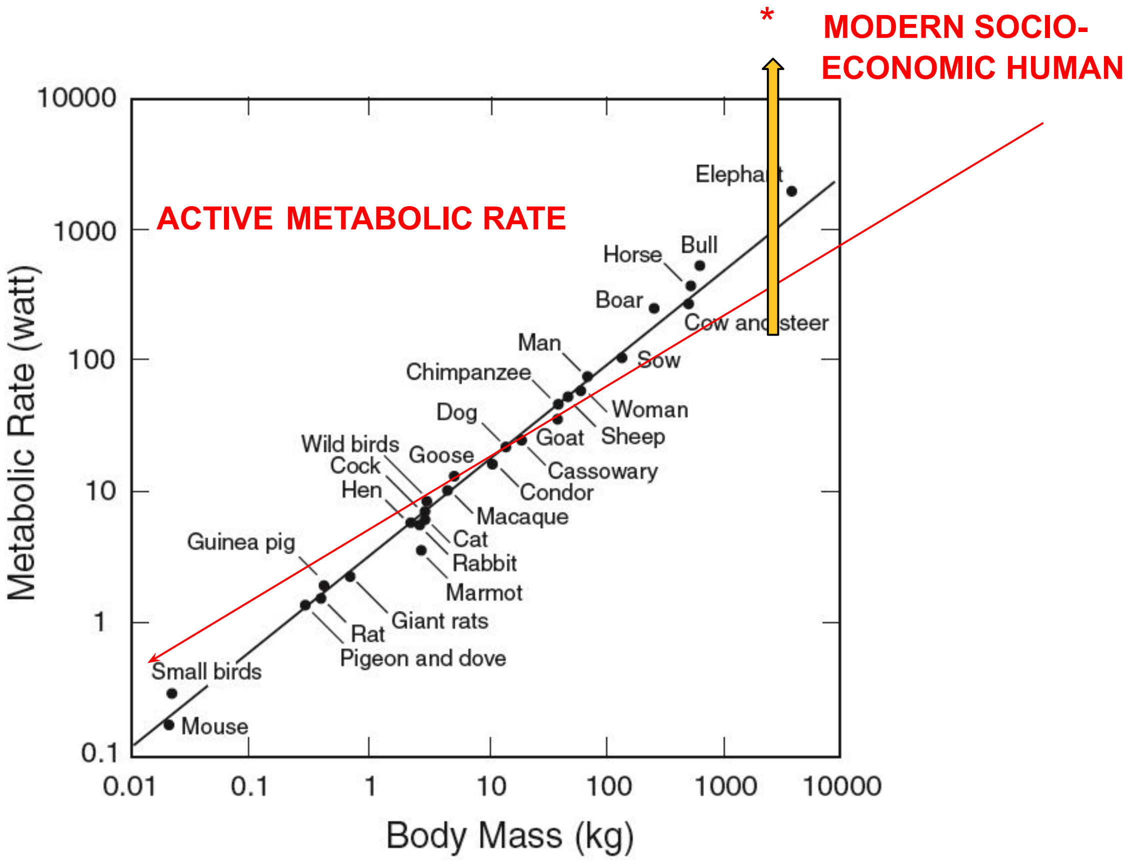
FOR MODERN HUMANS, ACTIVE METABOLIC RATE

≈ SOCIAL METABOLIC RATE (*Y*)

THIS IS THE RATE AT WHICH ENERGY, IN ITS BROADEST SENSE, NEEDS TO BE SUPPLIED IN ORDER TO:

i) MAINTAIN THE SOCIO-ECONOMIC SYSTEM, INCLUDING ALL INFRASTRUCTURE AND INDIVIDUALS, IN ITS PRESENT STATE

i) EFFECT CHANGE BY GROWING OR DEVELOPING NEW INFRASTRUCTURE, PEOPLE, IDEAS, INSTITUTIONS, ETC, ETC



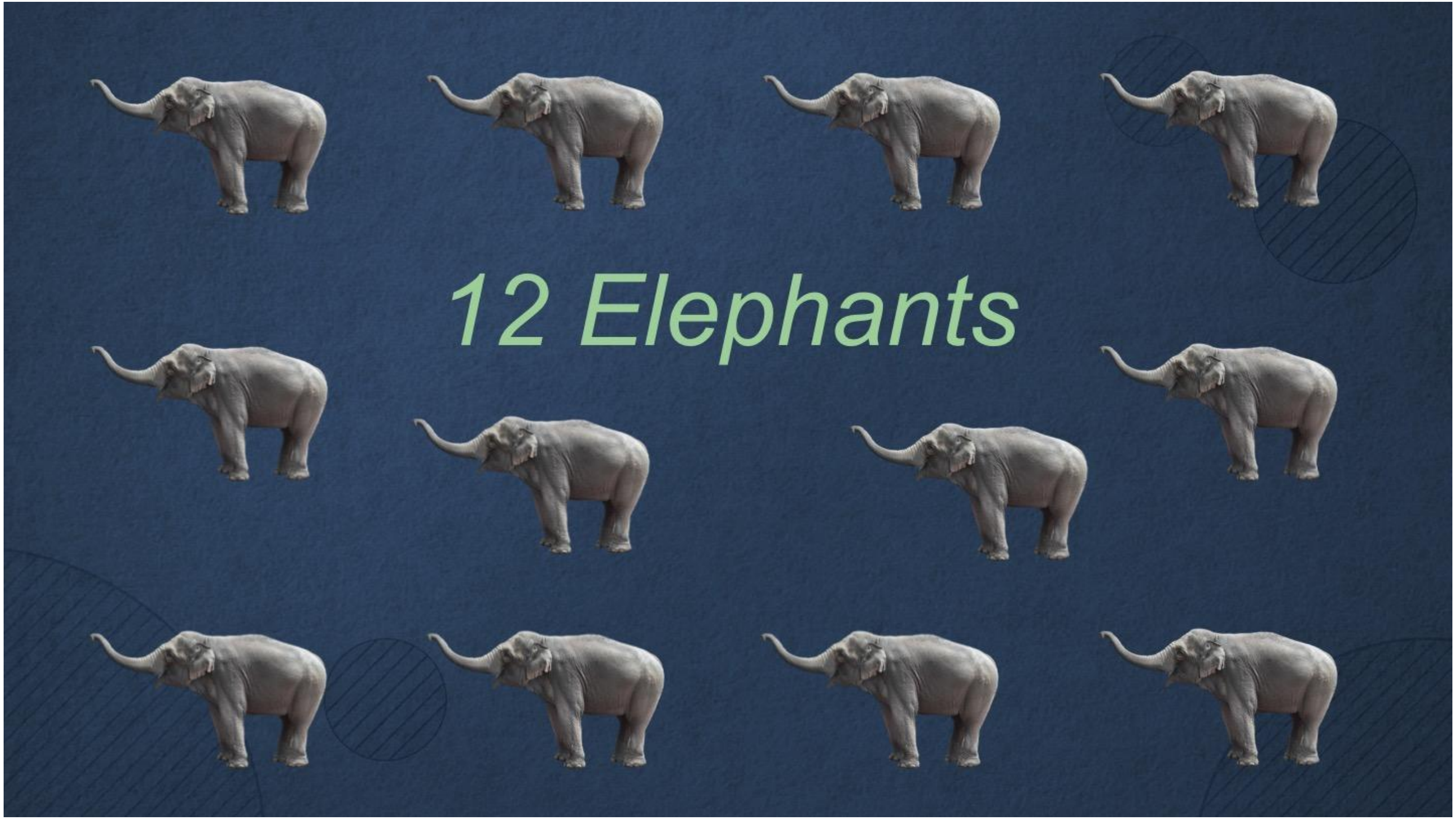
*
MODERN SOCIO-
ECONOMIC HUMAN
ACTIVE METABOLIC RATE
Metabolic Rate (watt)
10000
1000
100
10
1
0.1
0.01
0.1
1
10
100
1000
10000
Body Mass (kg)
Elephant
Bull
Horse
Boar
Cow and steer
Man
Sow
Chimpanzee
Woman
Dog
Sheep
Goat
Wild birds
Goose
Cock
Cassowary
Hen
Condor
Macaque
Cat
Guinea pig
Rabbit
Marmot
Giant rats
Rat
Pigeon and dove
Small birds
Mouse

Our “natural” metabolic rate *~90 watts*

Our social metabolic rate *~11,000 watts*

We are equivalent to a

30,000 kg Gorilla


12 Elephants

TIME EVOLUTION (GROWTH) OF THE TECHNOSPHERE

SOCIAL METABOLIC RATE

(RATE AT WHICH ENERGY, IN ITS BROADEST SENSE, IS SUPPLIED FOR)

= *MAINTENANCE*

(OF THE SOCIO-ECONOMIC SYSTEM IN ITS PRESENT STATE, INCLUDING ALL INFRASTRUCTURE AND INDIVIDUALS)

+

NEW GROWTH

(ADDING NEW INFRASTRUCTURE, PEOPLE, IDEAS, INSTITUTIONS, ETC, ETC)

BORROWING THE CONCEPT OF AN

"EXTENDED PHENOTYPE"

FROM BIOLOGY, EXPRESS THIS IN TERMS OF THE ENERGY BUDGET OF

"*EXTENDED* INDIVIDUALS"

WHICH INCLUDES THEIR ASSOCIATED PHYSICAL AND SOCIAL INFRASTRUCTURE AND INTERACTIONS

SUPPLY MAINTENANCE GROWTH

i) IN SOME SMALL TIME INTERVAL Δt THE SUPPLY OF SOCIAL METABOLIC ENERGY IS

$$Y(N)\Delta t = \left[\sum_{j=1}^{N} R_j(N)\right] \Delta t + \sum_{j=N}^{N+\Delta N} E_j(N)$$

R_j (N) = RATE AT WHICH THESE RESOURCES ARE USED BY THE j^{th} INDIVIDUAL TO MAINTAIN HIS/HER/ITS LIFE-STYLE, ETC)

E_j (N) = COST OF ADDING THE j^{th} INDIVIDUAL TO THE POPULATION

ii) AVERAGE AND TOTAL COSTS

$$\bar{R}(N) \equiv \frac{R(N)}{N} = \frac{1}{N}\sum_{j=1}^{N} R_j(N)$$

FOR BASAL MAINTENANCE

$$\bar{E}(N) \equiv \frac{E(N)}{N} = \frac{1}{N}\sum_{j=1}^{N} E_j(N)$$

FOR ADDING NEW INDIVIDUAL

$$\frac{dE(N)}{dt} = Y(N) - R(N)$$

LEADING TO

$$\frac{dN}{dt} = \frac{N}{\beta_E(N)}\left[\frac{Y(N) - R(N)}{E(N)}\right]$$

iii) WHICH CAN BE EXPRESSED AS

$$\beta_E(N) \equiv \frac{d\ln E(N)}{d\ln N}$$

THE ANTHROPOCENE EQUATION REDUCES TO

$$\frac{dN}{dt} = \frac{N}{\beta_E T}\left[\frac{Y(N)}{R(N)} - 1\right]$$

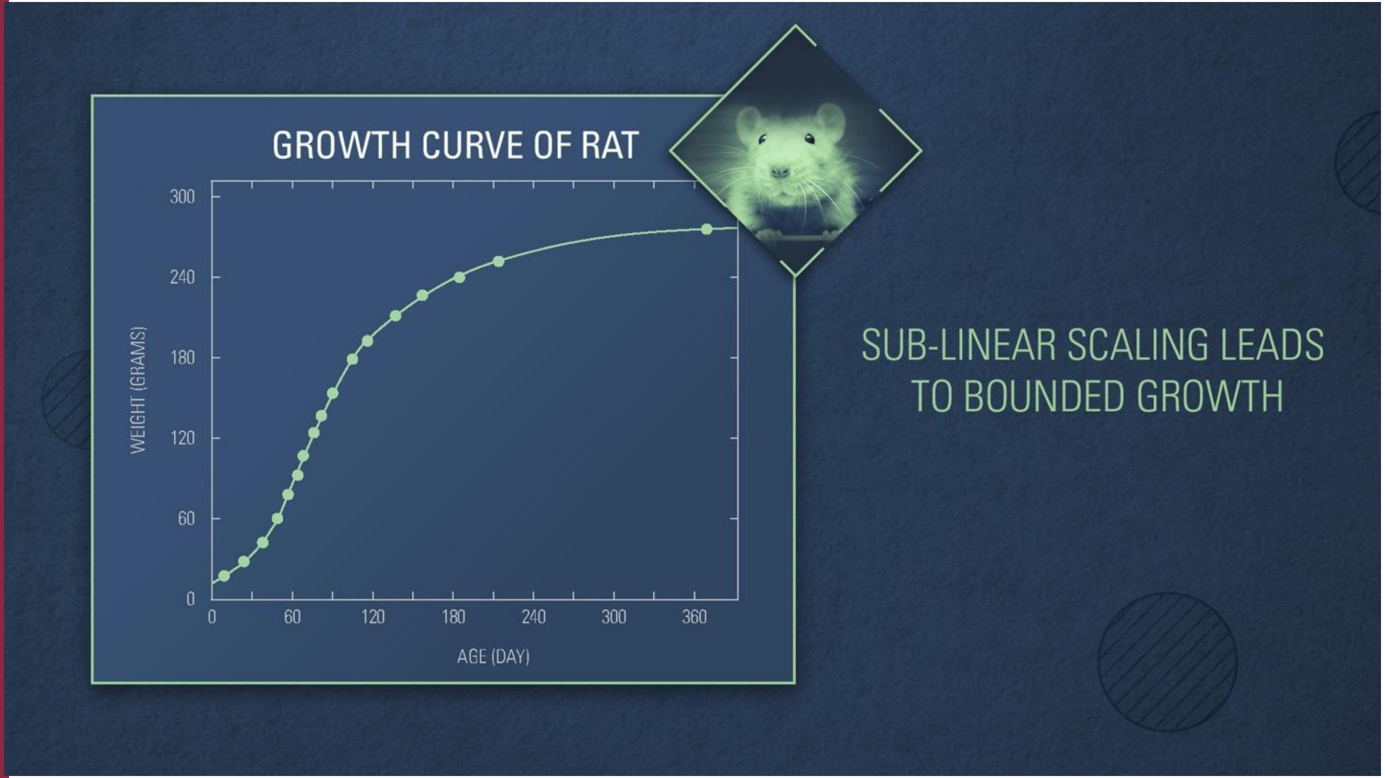
WHERE

$$\beta_E(N) \equiv \frac{d\ln E(N)}{d\ln N}$$

IN THE BIOSPHERE

MAINTENANCE NEEDS (DEMAND) GROW FASTER THAN SUPPLY (METABOLIC RATE IS SUB-LINEAR)

$\Longrightarrow$ GROWTH EVENTUALLY CEASES LEADING TO A FINITE SIZE OR FINITE CARRYING CAPACITY

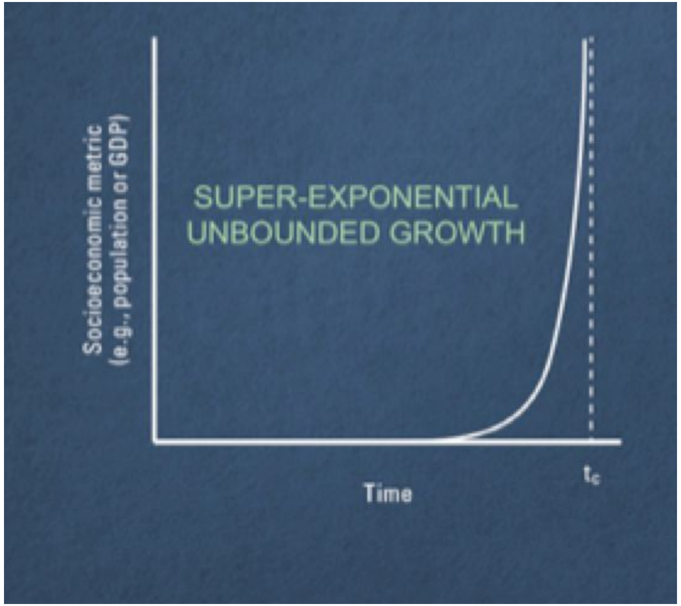

GROWTH CURVE OF RAT
300
240
180
120
60
0
WEIGHT (GRAMS)
0
60
120
180
240
300
360
AGE (DAY)
SUB-LINEAR SCALING LEADS
TO BOUNDED GROWTH

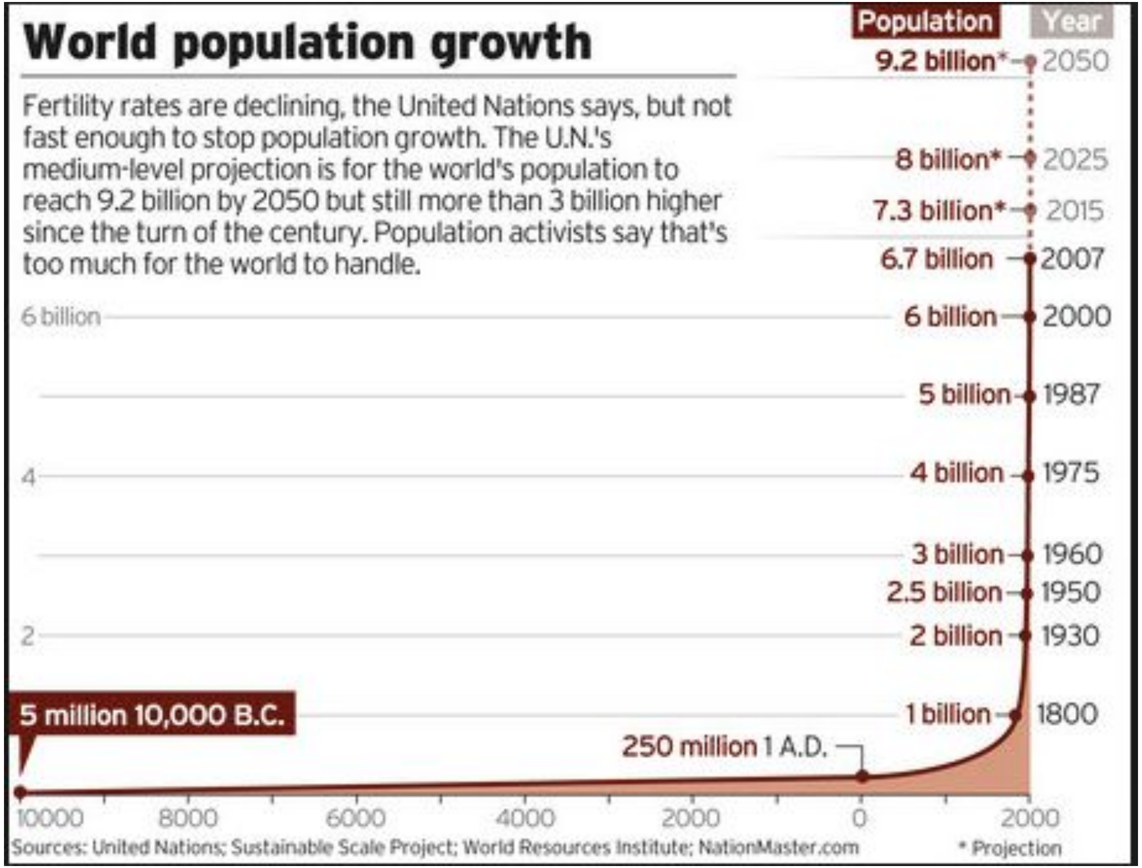
IN THE TECHNOSPHERE

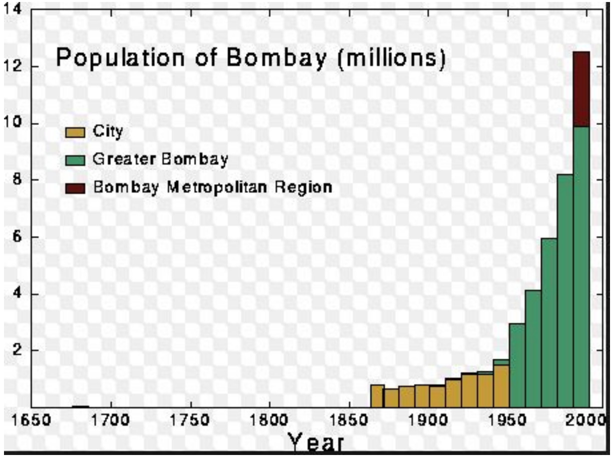
SUPER-LINEAR SOCIAL METABOLIC RATE (THE SUPPLY) GROWS FASTER THAN MAINTENANCE NEEDS (THE DEMAND)

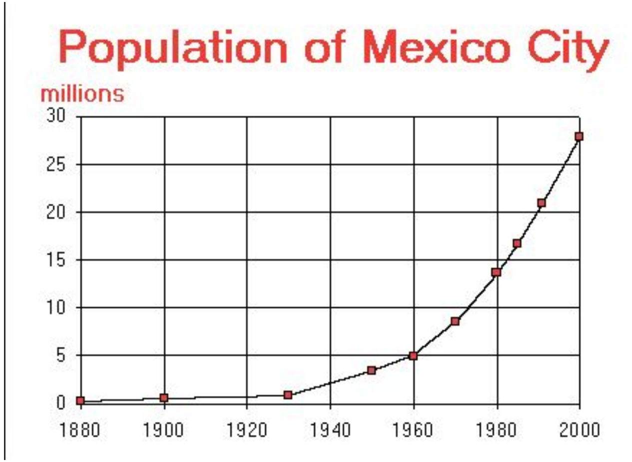
$\Longrightarrow$ OPEN-ENDED GROWTH

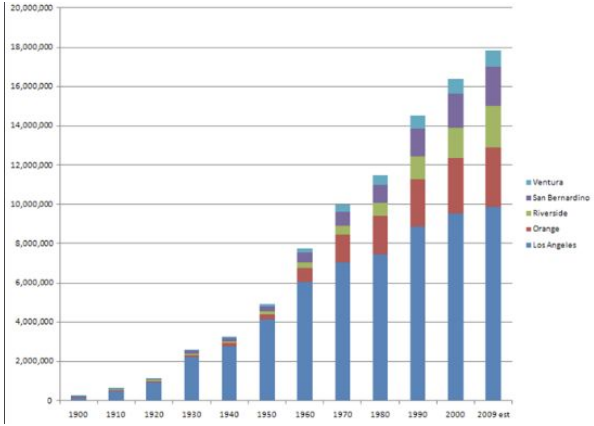
SUPERLINEAR SCALING LEADS TO UNBOUNDED GROWTH

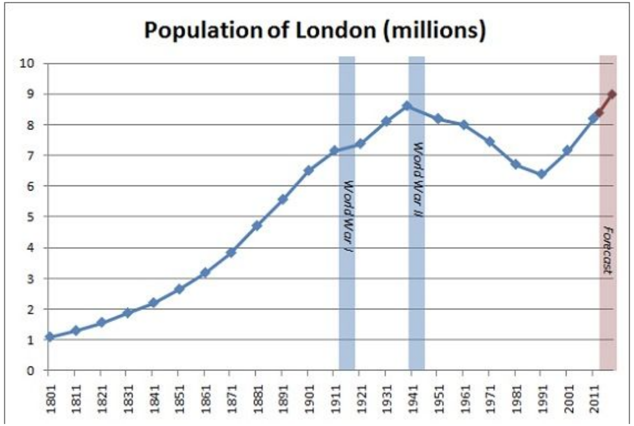


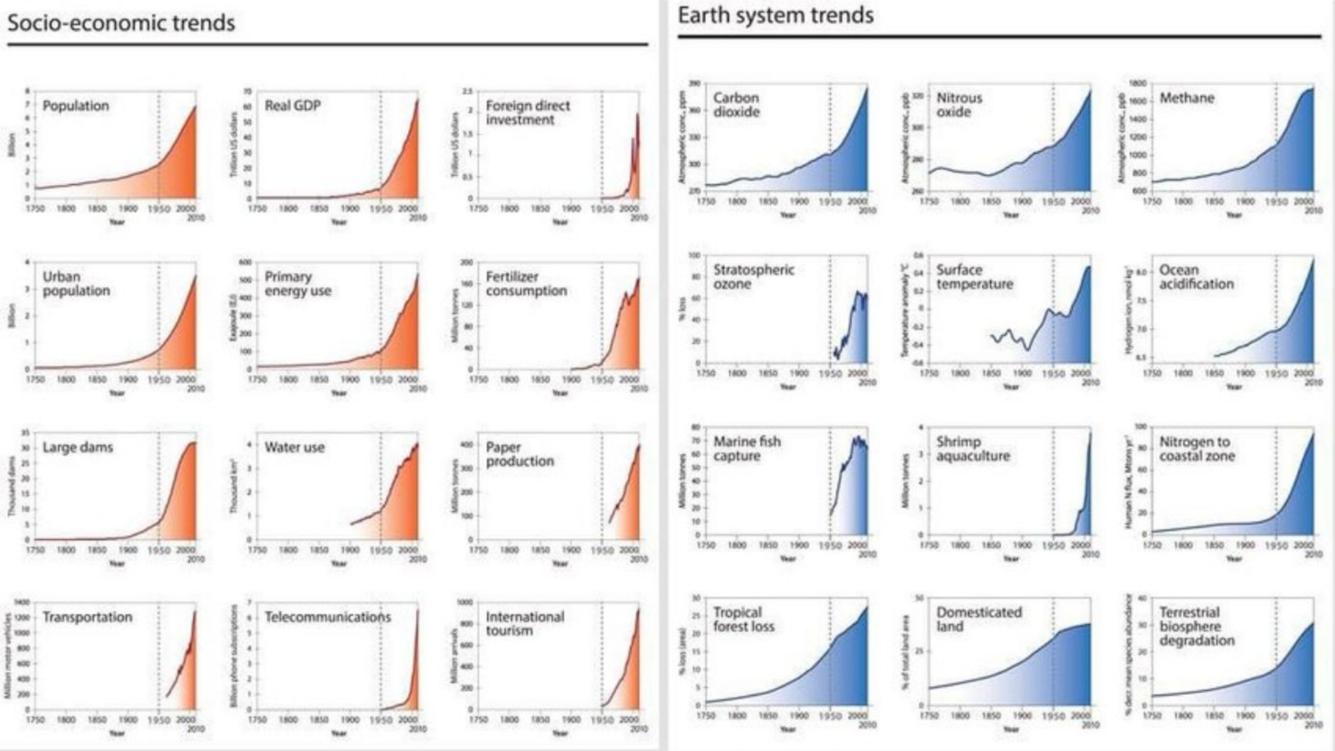

World population growth
Fertility rates are declining, the United Nations says, but not fast enough to stop population growth. The U.N.'s medium-level projection is for the world's population to reach 9.2 billion by 2050 but still more than 3 billion higher since the turn of the century. Population activists say that's too much for the world to handle.
Population
Year
9.2 billion* 2050
8 billion* 2025
7.3 billion* 2015
6.7 billion 2007
6 billion 2000
5 billion 1987
4 billion 1975
3 billion 1960
2.5 billion 1950
2 billion 1930
1 billion 1800
250 million 1 A.D.
5 million 10,000 B.C.
6 billion
4
2
10000
8000
6000
4000
2000
0
2000
Sources: United Nations; Sustainable Scale Project; World Resources Institute; NationMaster.com
* Projection


Population of Bombay (millions)
City
Greater Bombay
Bombay Metropolitan Region
14
12
10
8
6
4
2
1650
1700
1750
1800
1850
1900
1950
2000
Year


Population of Mexico City
millions
30
25
20
15
10
5
0
1880
1900
1920
1940
1960
1980
2000


20,000,000
18,000,000
16,000,000
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2009 est
Ventura
San Bernardino
Riverside
Orange
Los Angeles

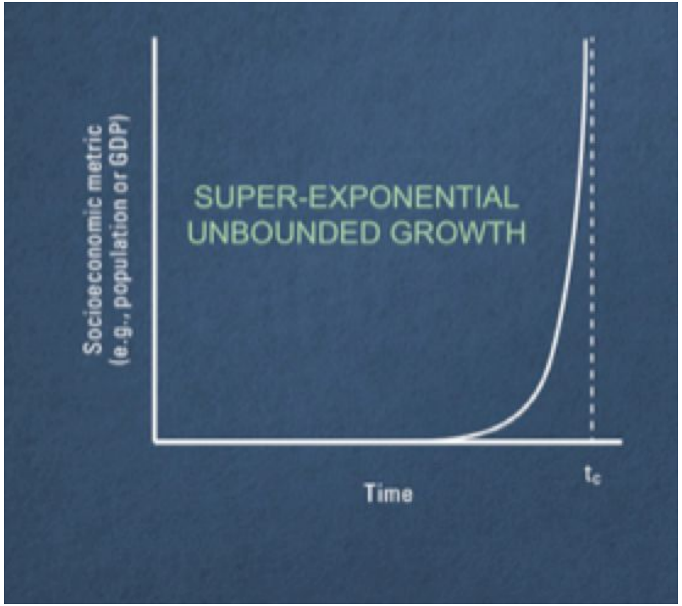

Population of London (millions)
10
9
8
7
6
5
4
3
2
1
0
World War I
World War II
Forecast
1801
1811
1821
1831
1841
1851
1861
1871
1881
1891
1901
1911
1921
1931
1941
1951
1961
1971
1981
1991
2001
2011



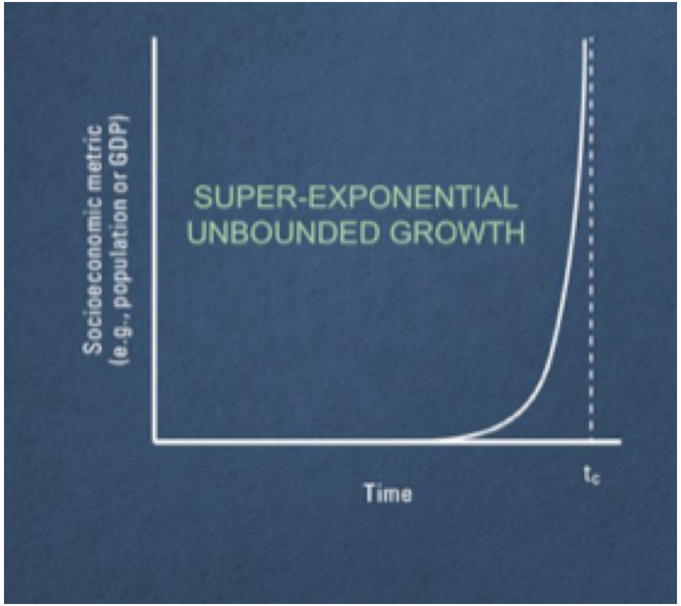
Updated Great Acceleration Graphs

Source: Will Steffen et al. "The trajectory of the Anthropocene: The Great Acceleration." The Anthropocene Review, March 2015

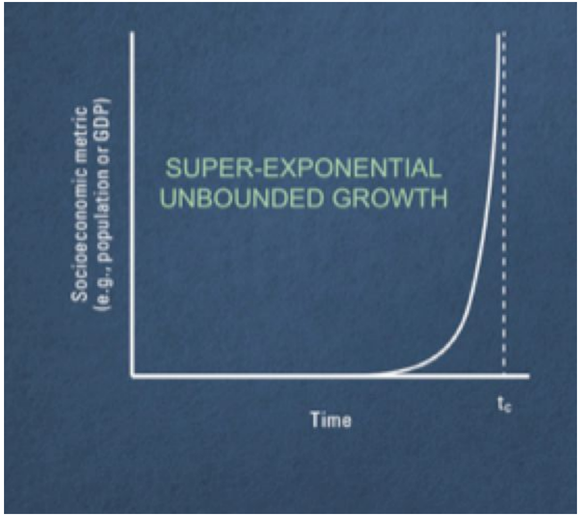
BUT IT ALSO LEADS TO

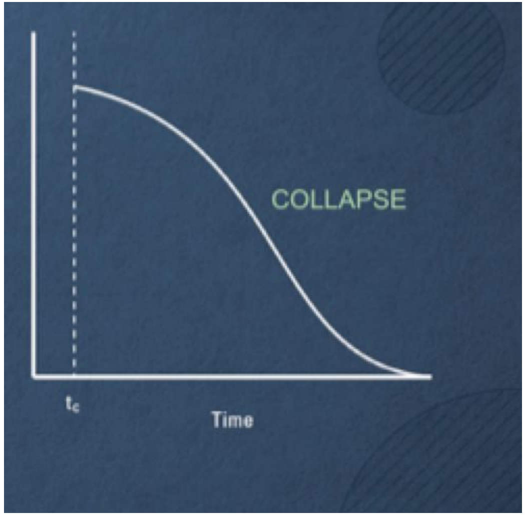


A FINITE TIME SINGULARITY AT $t = t_c$

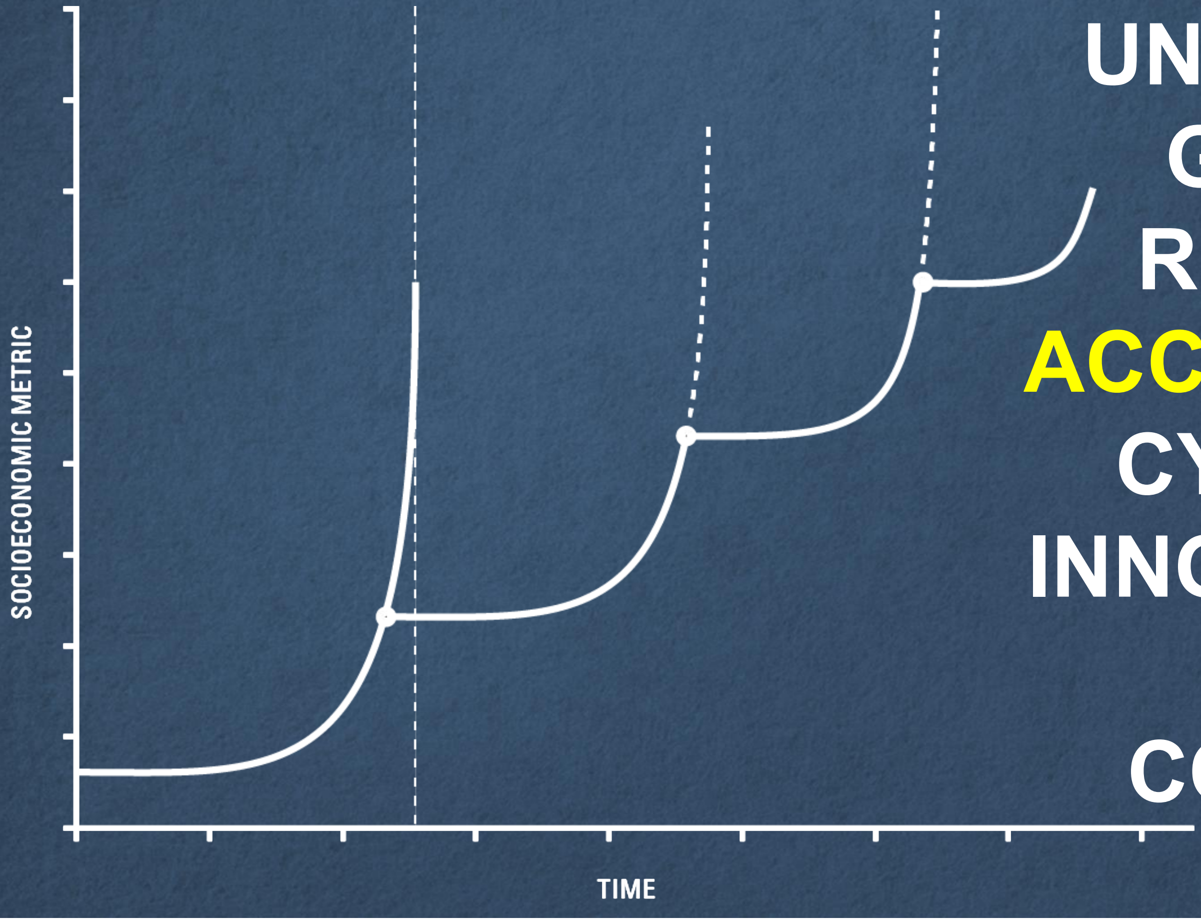


AND COLLAPSE WHEN $t > t_c$

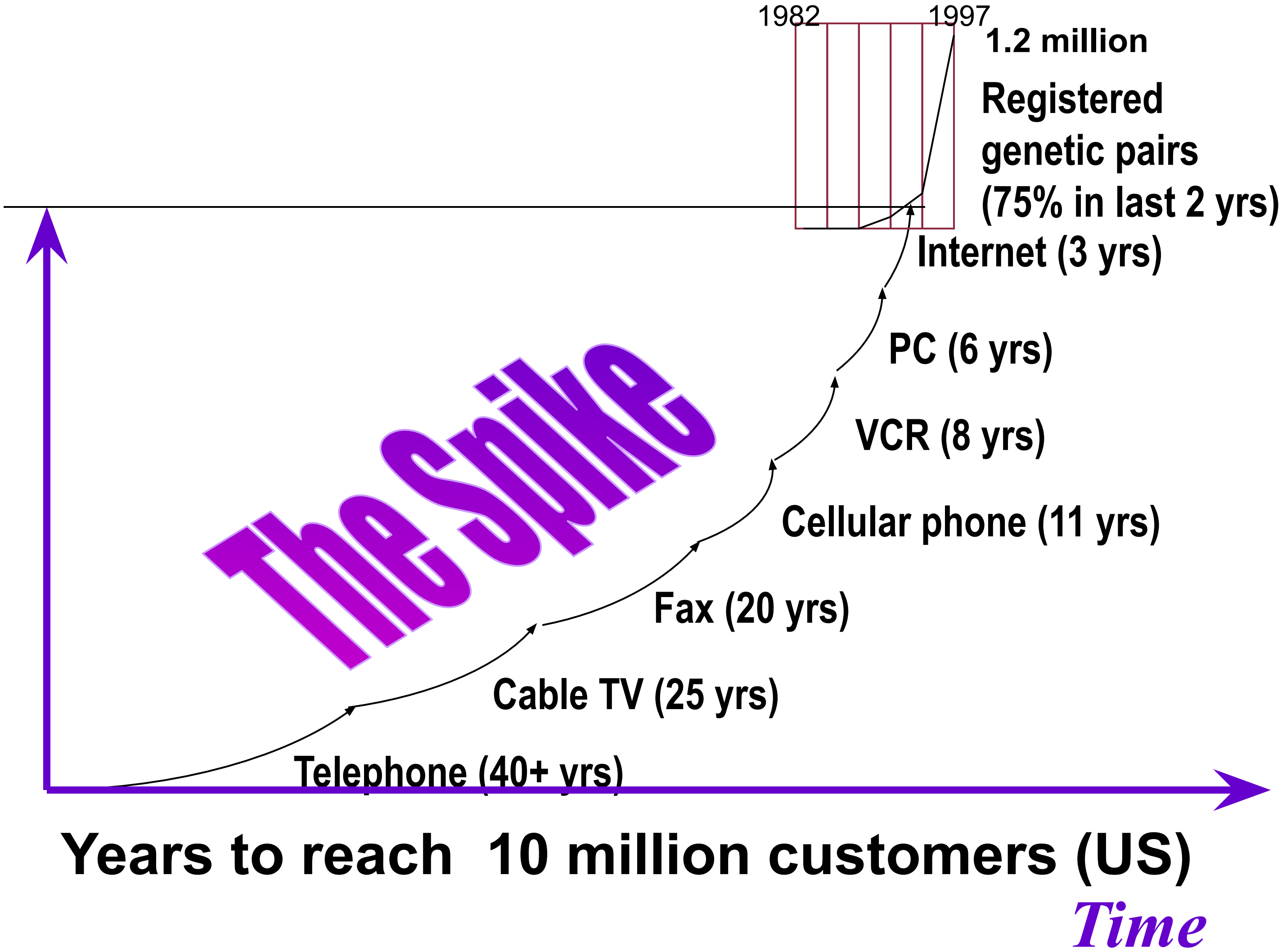


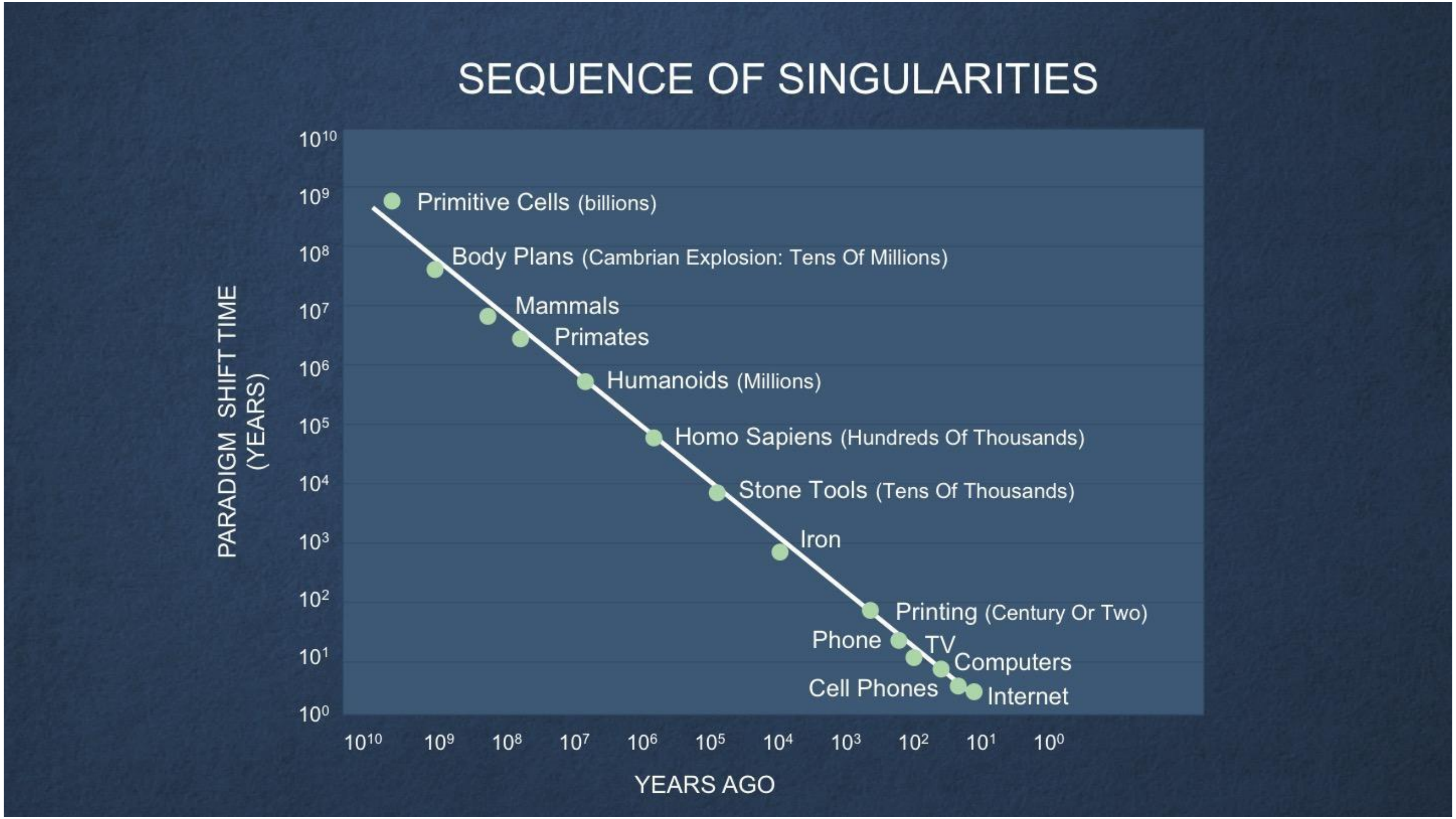


THE NOT SUCH GOOD NEWS!



UNBOUNDED GROWTH REQUIRES ACCELERATING CYCLES OF INNOVATION TO AVOID COLLAPSE


1982
1997
1.2 million
Registered genetic pairs
(75% in last 2 yrs)
Internet (3 yrs)
PC (6 yrs)
VCR (8 yrs)
Cellular phone (11 yrs)
Fax (20 yrs)
Cable TV (25 yrs)
Telephone (40+ yrs)
The Spike
Years to reach 10 million customers (US)
Time



SEQUENCE OF SINGULARITIES
PARADIGM SHIFT TIME (YEARS)
YEARS AGO
Primitive Cells (billions)
Body Plans (Cambrian Explosion: Tens Of Millions)
Mammals
Primates
Humanoids (Millions)
Homo Sapiens (Hundreds Of Thousands)
Stone Tools (Tens Of Thousands)
Iron
Printing (Century Or Two)
Phone
TV
Computers
Cell Phones
Internet

POWER LAW APPROXIMATION (MOTIVATED BY NETWORKS & DATA)

$$\begin{aligned} Y(N) &= Y_0 N^{\beta} \\ R(N) &= R_0 N^{\beta_R} \\ E(N) &= E_0 N^{\beta_E} \end{aligned}$$

LEADS TO "EXACT" SOLUTION

$$N(t) = \left(\frac{R_0}{Y_0}\right)^{1/\gamma} \left[\frac{1}{1 - e^{-(t_c - t)/T_0}}\right]^{1/\gamma}$$

WHER $\gamma \equiv \beta - \beta_R$ AND THE SINGULARITY AT $t = t_c$ IS GIVEN BY

$$t_c - t_0 \approx \left[\frac{1}{N_0^{\gamma}} \frac{R_0}{Y_0}\right] T_0 = \left[\frac{R(N_0)}{Y(N_0)}\right] T_0$$

THE APPROACH TO THE SINGULARITY AS $t \to t_c$

$$N(t) = \left(\frac{R_0}{Y_0}\right)^{1/\gamma} \left[\frac{T_0}{t_c - t}\right]^{1/\gamma}$$

THEORY PREDICTS THAT LOGARITHMIC

PLOTS OF MAJOR SOCIO-ECONOMIC METRICS

(ENERGY, WATER,….) AGAINST THE TIME TO

THE NEXT SINGULARITY:

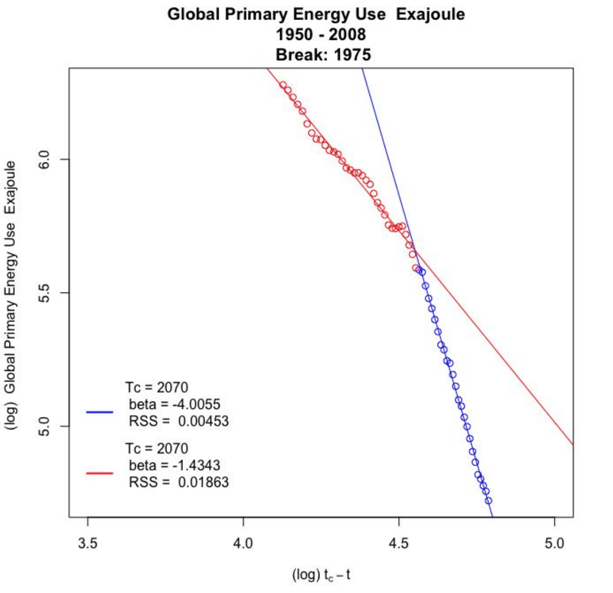
$$\log Y(t) \text{ vs. } \log (t_c - t)$$

SHOULD YIELD STRAIGHT LINES WITH PREDICTED

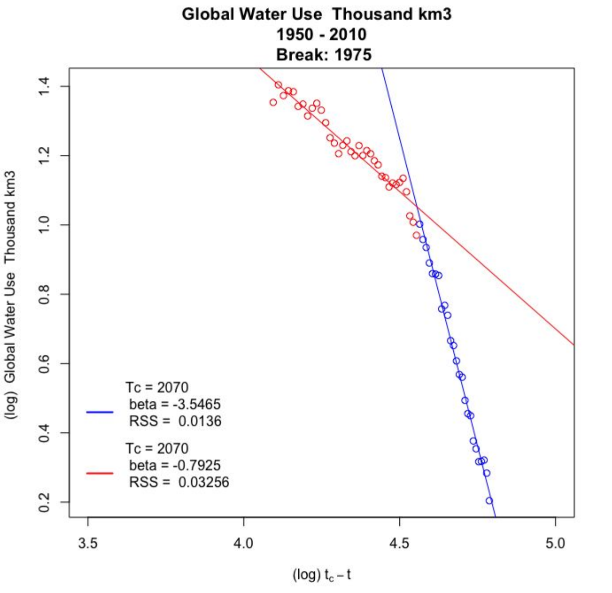
VALUES OF THE SLOPES AND INTERCEPTS

When will we reach the next singularity?

GLOBAL ENERGY USE



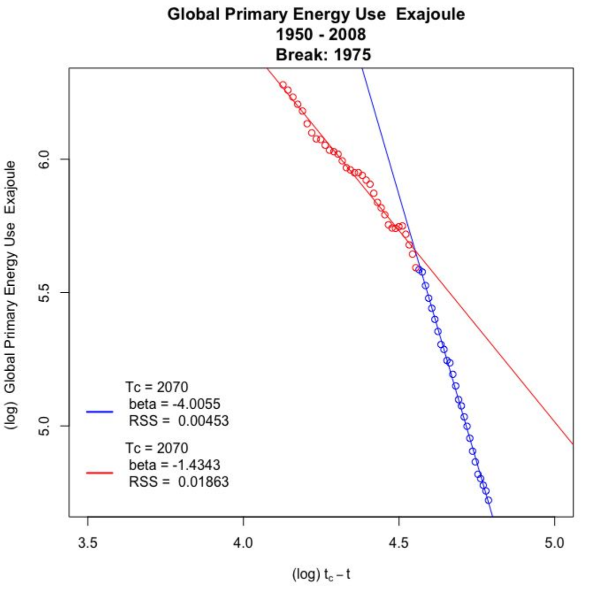
GLOBAL WATER USE



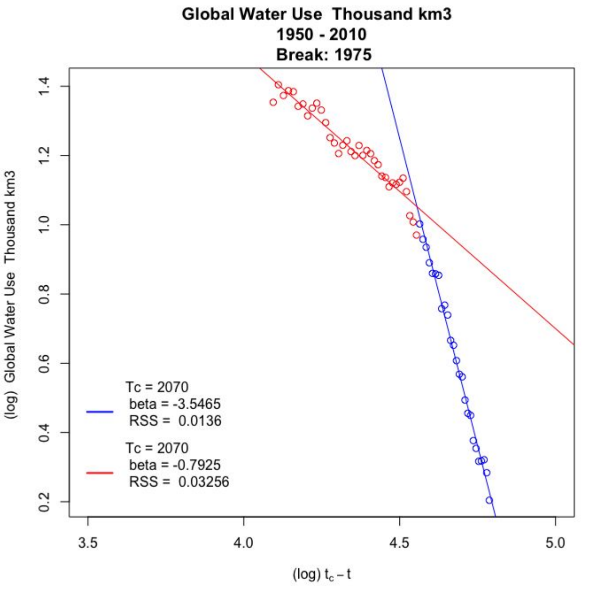
SUGGESTS THERE WAS A SIGNIFICANT "PARADIGM SHIFT" AND WE AVOIDED A SINGULARITY IN MID-1970'S (AROUND 1975)

SPECULATIONS?

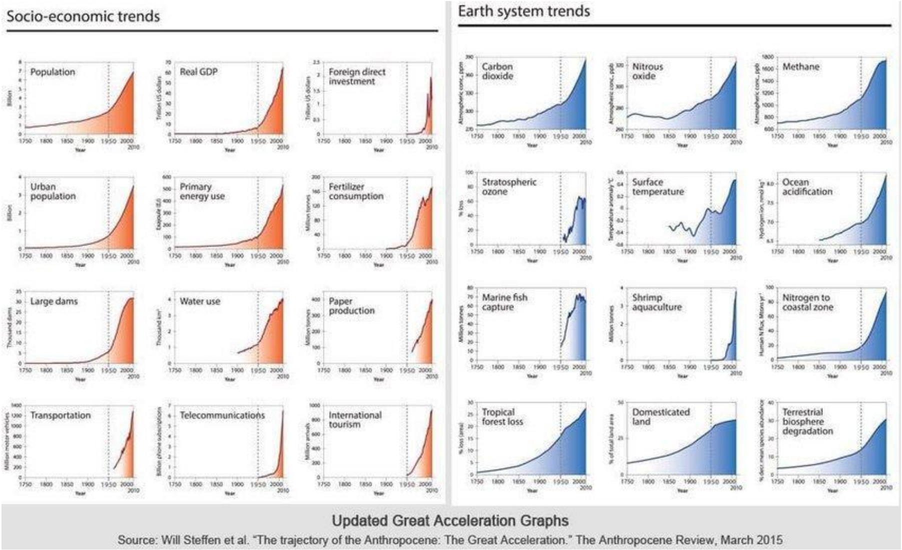
GLOBAL ENERGY USE



GLOBAL WATER USE



WHY 1975 MATTERS?



The phenotype of the Great Acceleration

However, once we analyzed this in the context of the Anthropocene Equation

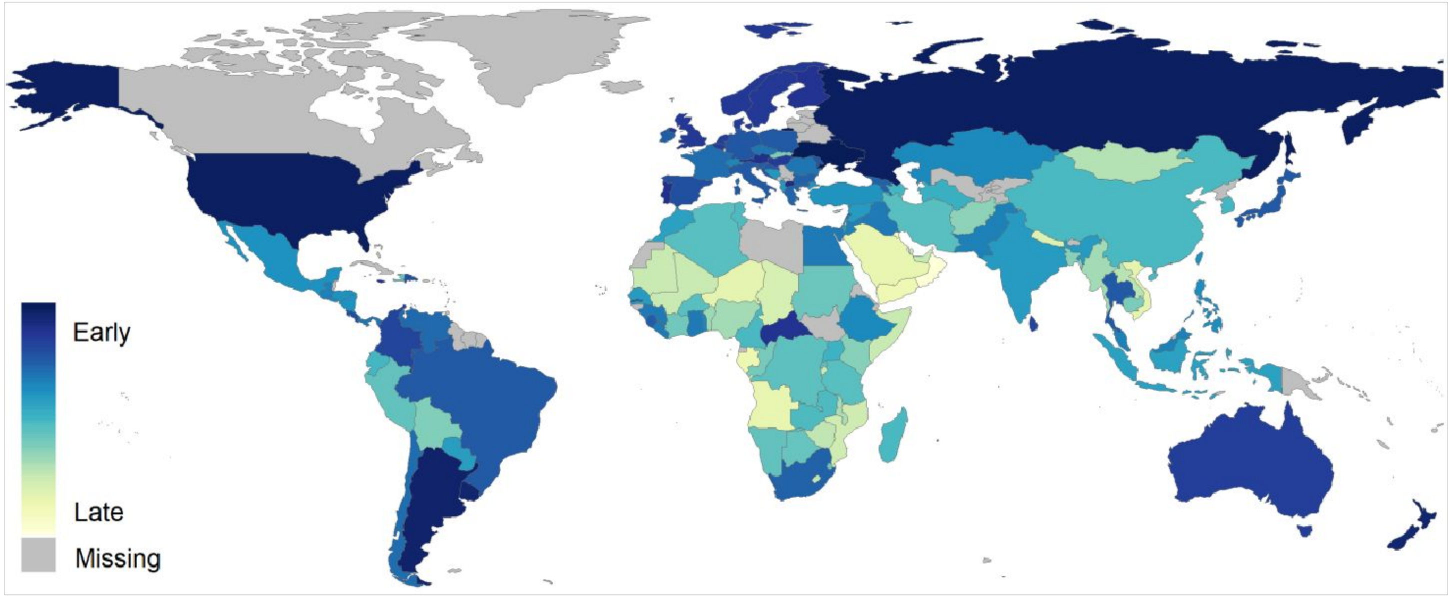
We found that most of these time series have a breaking point around 1975

Breakpoint Analysis and Regression Data

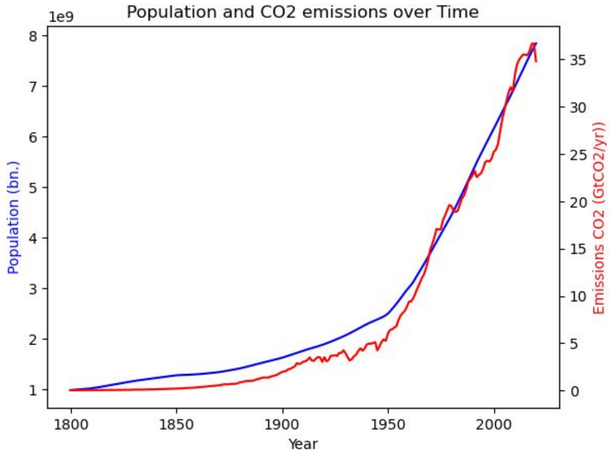
	Bkpt.	(b) T_c	(b) α	(b) β	(b) RSS	(a) T_c	(a) α	(a) β	(a) RSS
Pop	1990	2070	9.9579	−1.8825	0.00754	2070	5.3777	−0.8411	0.00181
GDP	1975	2030	16.8496	−3.4522	0.009	2070	12.8135	−2.1577	0.0257
FDI	1976	2030	45.9047	−12.4274	4.211	2070	40.8427	−9.7455	4.1214
Energy	1976	2070	23.6423	−3.9532	0.0071	2070	12.0791	−1.4092	0.0144
Fertilizer	1976	2070	41.0339	−8.0031	0.0588	2070	8.808	−0.9034	0.1452
Dams	1976	2070	27.5555	−5.3904	0.0205	2070	7.3844	−0.9358	0.1108
Water	1976	2070	16.818	−3.464	0.02	2070	4.5376	−0.763	0.0249
Paper	1976	2070	27.5113	−4.9343	0.0626	2070	15.5778	−2.3176	0.0866
Cars	1975	2070	31.1649	−5.5566	0.0032	2070	18.7008	−2.8096	0.137
Phones	1960	2030	150.4055	−36.0515	4.2076	2030	12.0812	−3.4157	0.8229
Tourism	1974	2070	53.2723	−10.4434	0.0129	2070	20.3643	−3.2765	0.0912
CO_2 ppb	1975	2030	6.3865	−0.1481	0.0001	2070	7.3671	−0.3443	0.0001
CO_2 emm.	1975	2070	38.3286	−4.7437	0.0038	2030	19.1967	−0.6279	0.029
NO_2 ppb	1975	2030	6.063	−0.0913	< 0.0001	2070	6.4724	−0.1693	< 0.0001
NO_2 emm.	1985	2070	23.2238	−1.8763	0.0148	2030	15.2467	−0.1009	0.0411
NH_4 ppb	2005	2070	10.8704	−0.7966	0.0639	2070	8.2579	−0.193	< 0.0001
NH_4 emm.	1975	2070	19.0718	−0.7818	0.001	2030	16.7394	−0.2914	0.0383
Ozone	1990	2070	31.4243	−6.2237	2.6573	2070	2.97775	0.2674	0.3402
Temp.	2000	2070	48.7216	−11.5685	3.9842	2070	1.9832	−0.6672	0.0164
Oceans	1975	2030	2.4001	−0.1054	0.0001	2070	3.2059	−0.2686	0.0001
Fish	1985	2070	23.1329	−4.22	0.8764	2030	4.0347	0.0556	0.0351
Shrimp	1995	2070	70.0562	−16.1437	6.95956	2070	31.6365	−7.3796	0.25515
Forests	1975	2070	7.7973	−1.0383	0.0109	2070	5.8471	−0.617	0.0015
Dom. Land	1975	2070	1.5169	−0.5538	0.0057	2070	−0.4229	−0.131	0.0023
EPO Pat.	1985	2070	122.8245	−25.2107	0.9996	2070	19.2434	−1.9703	0.4205
USPTO Pat.	1975	2070	29.7506	−4.0308	0.0905	2030	16.0729	−1.2328	1.6252
WoS Pubs.	1975	2070	55.2422	−9.2019	0.2478	2030	17.6028	−1.053	0.1233

Table 2: **Breakpoint Regression Data.** *(b)* = Pre-breakpoint, *(a)* = Breakpoint and beyond.

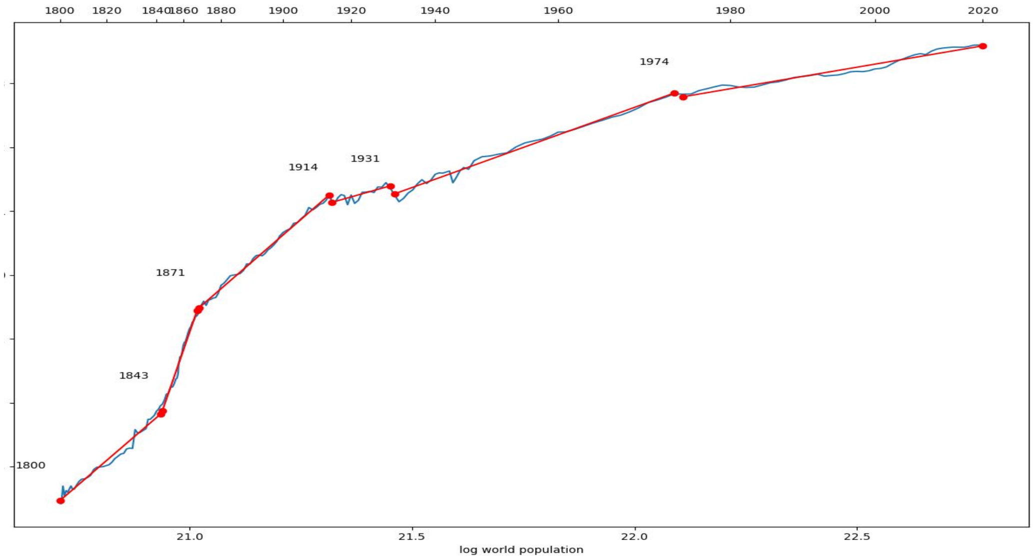
Waves of acceleration: timing of largest acceleration events —Jonathan Donges



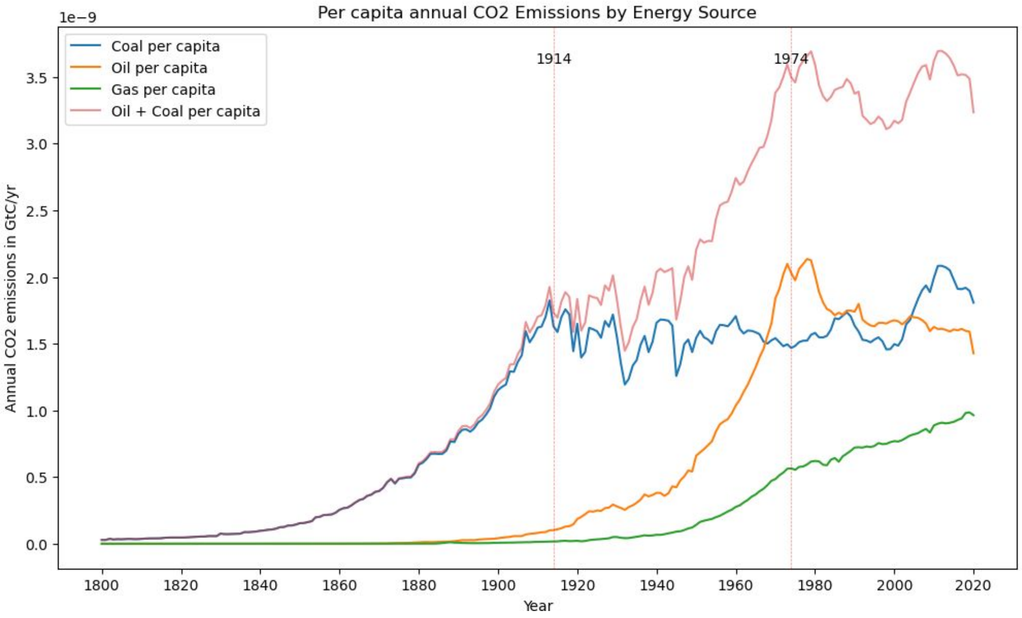
Examining the Relationship Between Population Growth and CO2 Emissions from Fossil Fuels—Jochen Büttner



Population Growth and CO2 Emissions from Fossil Fuels - scaling analysis



Population Growth and CO2 Emissions from Fossil Fuels - The 1914 macro-level shift



Crucial Observations/Lessons

- Complex evolving systems are governed by regulatory structures
- Complex evolving systems construct their niches
- These dynamics introduce feedback into these systems
- Dynamically stable systems have the right balance between positive and negative feedback loops

Elimination of negative feedback in the course of human history

- Starting in the Neolithic humans began to eliminate negative feedback
- They closed the positive feedback loop between population – knowledge – energy, or the Anthropocene (innovation) engine
- As a consequence, we see the continuous acceleration of human history and the emancipation of humans from their environment
- The current crisis is the culmination of these trends

What can be done?

- Introducing negative feedback into the system
- Values, norms, laws and regulations make up the social regulatory system of humanity
- Hierarchical and lateral regulation
- Nation states and global civil society
- The role of (scientific) knowledge
- Broad, integrative and transdisciplinary knowledge

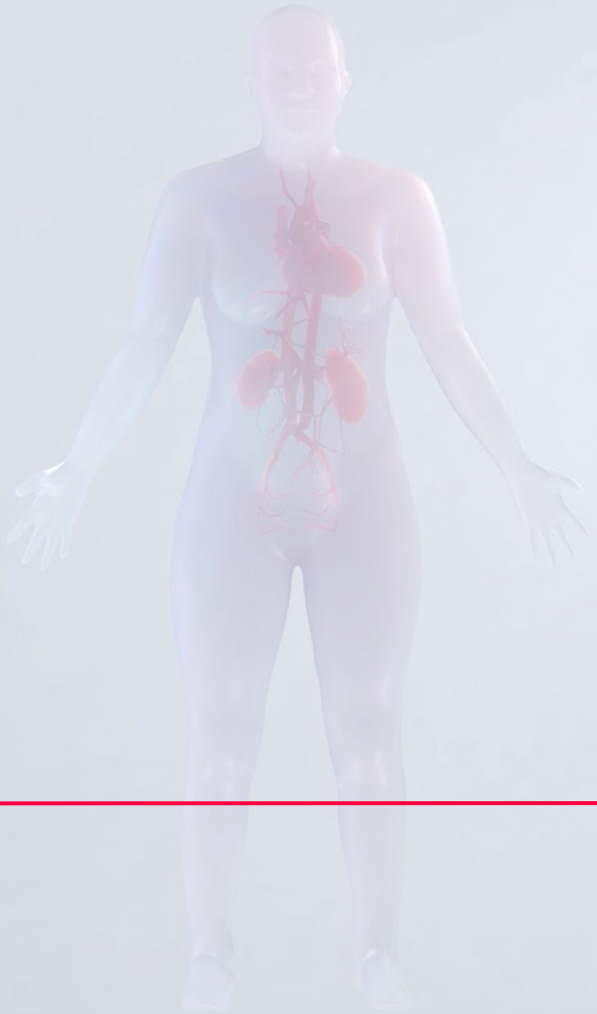
How can it be done?

School of Complex Adaptive Systems
Arizona State University

Thank You

Collaborators:
Günter Wagner, Rob Page, Jürgen Gadau, Peter Stadler, Carlo Jäger, Chris Kempes, Deryc Painter, Jürgen Renn, Peter Schlosser, Geoffrey West, Ricarda Winkelmann, Patrick Roberts, Chris Carleton, Sarah Wolf, Joffa Applegate

Q&A



https://humanatlas.io/events/2024-24h

Questions

How do we define a Multiscale Human?

How do we map a Multiscale Human?

How do we model a Multiscale Human?

How can LLMs or RAGs be used to advance science and clinical practice?

Thank you