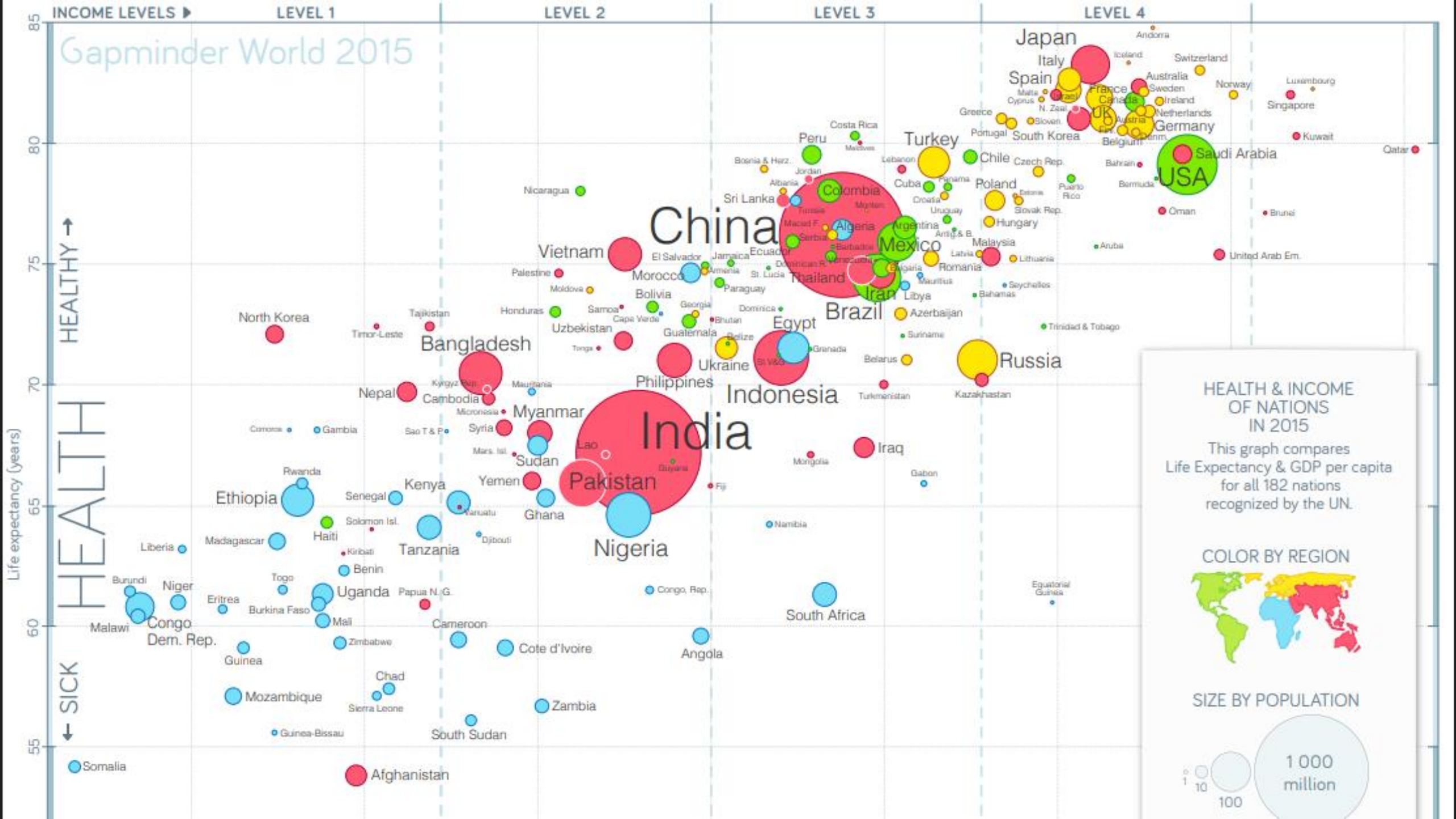
FOR BETTER AND FOR WORSE

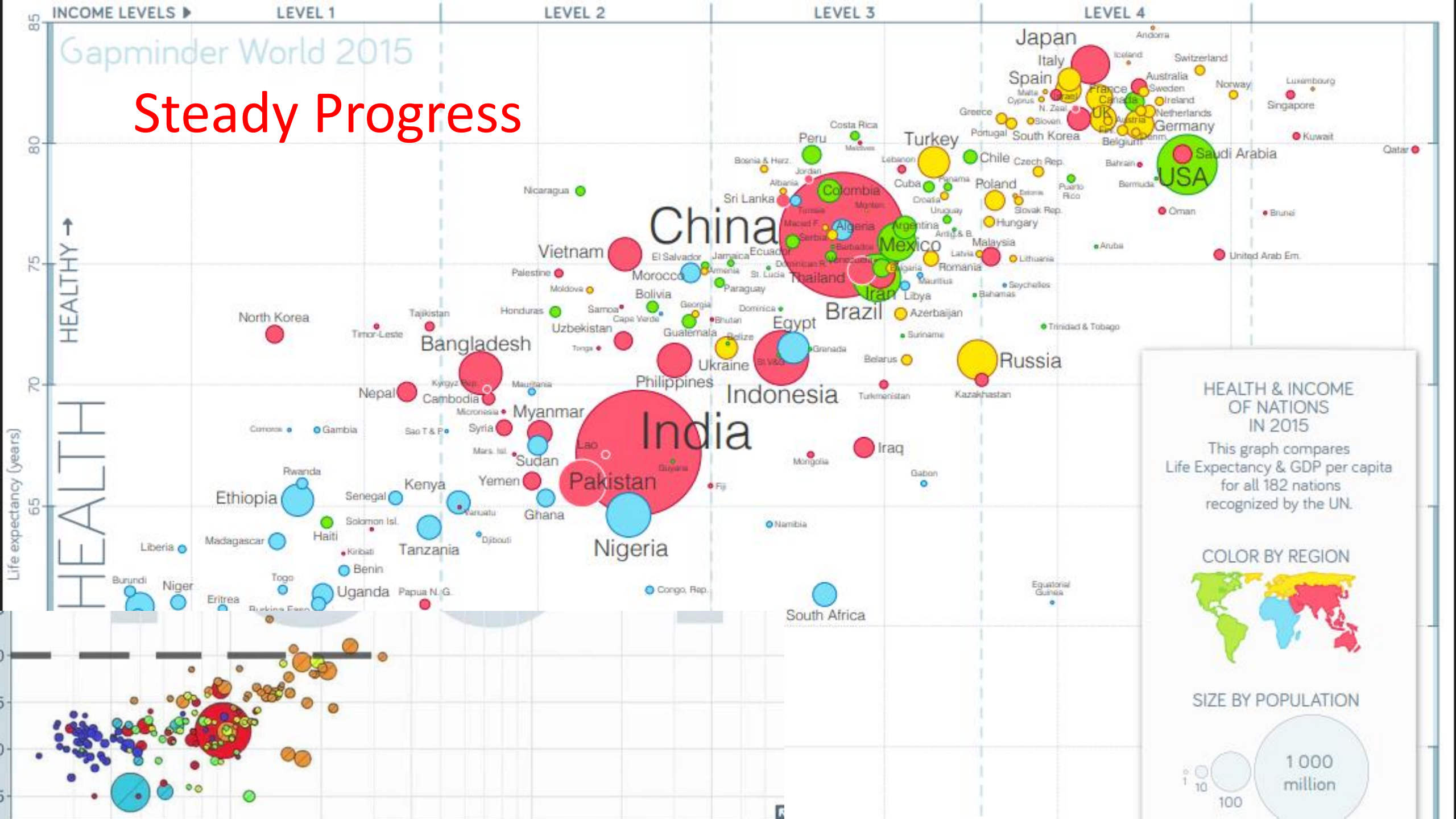
Externality shifting explains Paradox

Thomas Sterner +

Gothenburg
Sweden

Apocalypse Now


INCOME LEVELS
LEVEL 1
LEVEL 2
LEVEL 3
LEVEL 4
Gapminder World 2015
HEALTHY →
← SICK
HEALTH
Life expectancy (years)
85
80
75
70
65
60
55
Japan
Italy
Spain
Andorra
Iceland
Switzerland
Australia
Sweden
Norway
Luxembourg
Singapore
France
Canada
Ireland
Netherlands
Germany
UK
Belgium
Greece
Portugal
South Korea
Slovenia
Cyprus
Malta
N. Zealand
Austria
Kuwait
Qatar
Saudi Arabia
USA
Peru
Costa Rica
Maldives
Turkey
Chile
Czech Rep.
Lebanon
Bosnia & Herz.
Jordan
Albania
Cuba
Panama
Poland
Estonia
Puerto Rico
Bahrain
Bermuda
Oman
Brunei
Nicaragua
Sri Lanka
Colombia
Croatia
Uruguay
Slovak Rep.
Hungary
Tunisia
Algeria
Argentina
Antig.& B.
Mexico
Malaysia
Latvia
Lithuania
Aruba
United Arab Em.
Vietnam
China
Ecuador
Barbados
Romania
Bulgaria
Mauritius
Seychelles
Bahamas
Morocco
El Salvador
Jamaica
Armenia
St. Lucia
Thailand
Palestine
Paraguay
Moldova
Bolivia
Iran
Libya
Brazil
Azerbaijan
Honduras
Samoa
Cape Verde
Georgia
Dominica
Bhutan
Egypt
Trinidad & Tobago
Suriname
Uzbekistan
Guatemala
Belize
Grenada
Tonga
Tajikistan
North Korea
Timor-Leste
Bangladesh
Ukraine
Belarus
Russia
Kazakhstan
Turkmenistan
Philippines
Indonesia
Kyrgyz Rep.
Mauritania
Nepal
Cambodia
Micronesia
Myanmar
Comoros
Gambia
Sao T & P.
Syria
India
Lao
Mars. Isl.
Sudan
Iraq
Mongolia
Gabon
Rwanda
Ethiopia
Kenya
Senegal
Yemen
Pakistan
Guyana
Fiji
Namibia
Solomon Isl.
Vanuatu
Ghana
Haiti
Tanzania
Nigeria
Madagascar
Djibouti
Liberia
Kiribati
Benin
Burundi
Niger
Togo
Uganda
Papua N. G.
Congo, Rep.
Equatorial Guinea
South Africa
Eritrea
Burkina Faso
Mali
Malawi
Congo Dem. Rep.
Cameroon
Cote d'Ivoire
Angola
Zimbabwe
Guinea
Chad
Mozambique
Sierra Leone
Zambia
South Sudan
Guinea-Bissau
Somalia
Afghanistan
HEALTH & INCOME OF NATIONS IN 2015
This graph compares Life Expectancy & GDP per capita for all 182 nations recognized by the UN.
COLOR BY REGION
SIZE BY POPULATION
1
10
100
1 000 million

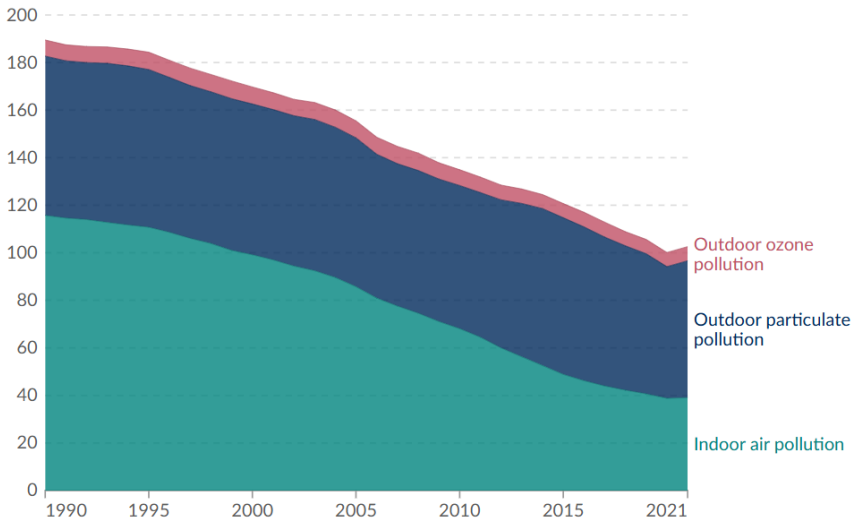

INCOME LEVELS
LEVEL 1
LEVEL 2
LEVEL 3
LEVEL 4
Gapminder World 2015
Steady Progress
HEALTHY →
HEALTH
Life expectancy (years)
85
80
75
70
65
Japan
Italy
Spain
Switzerland
Australia
Sweden
Norway
Ireland
Netherlands
Germany
Singapore
Kuwait
Qatar
Saudi Arabia
USA
Peru
Turkey
Chile
Poland
Hungary
Colombia
China
Vietnam
Mexico
Brazil
Malaysia
Thailand
Iran
Egypt
Russia
Indonesia
Philippines
Ukraine
India
Pakistan
Nigeria
Bangladesh
North Korea
Nepal
Cambodia
Myanmar
Sudan
Yemen
Ethiopia
Kenya
Ghana
Tanzania
Uganda
Rwanda
Senegal
Haiti
Madagascar
Liberia
Burundi
Niger
Togo
Benin
Eritrea
Uzbekistan
Morocco
Algeria
Argentina
Iraq
South Africa
HEALTH & INCOME OF NATIONS IN 2015
This graph compares Life Expectancy & GDP per capita for all 182 nations recognized by the UN.
COLOR BY REGION
SIZE BY POPULATION
1
10
100
1 000 million

Death rate from air pollution, World

Estimated annual number of deaths from outdoor ozone pollution, particulate pollution, and indoor fuel pollution per 100,000 people.

Our World in Data

Table | Chart | Edit | Settings

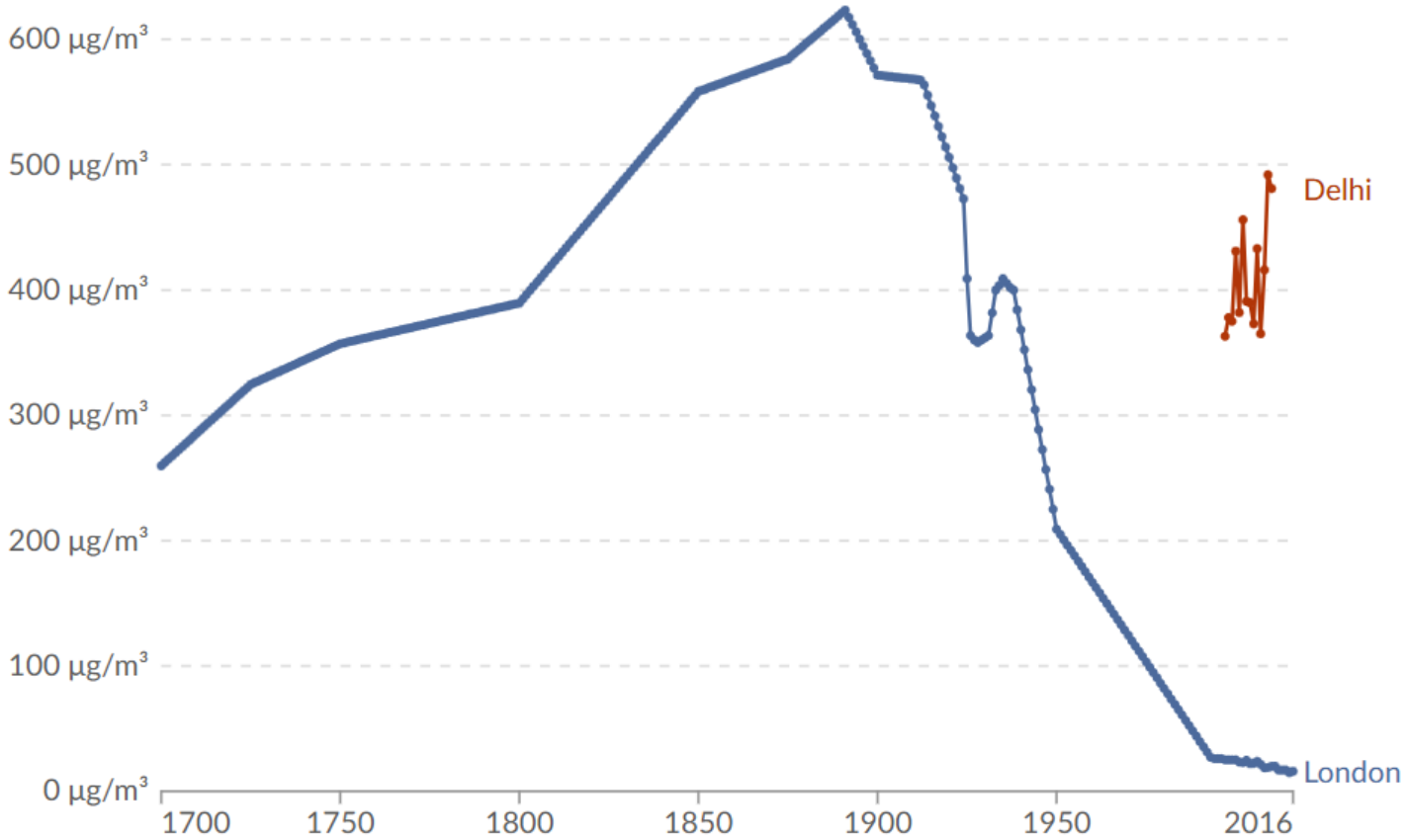


Air pollution, 1700 to 2016

Average concentrations of suspended particulate matter, measured in micrograms per cubic meter.

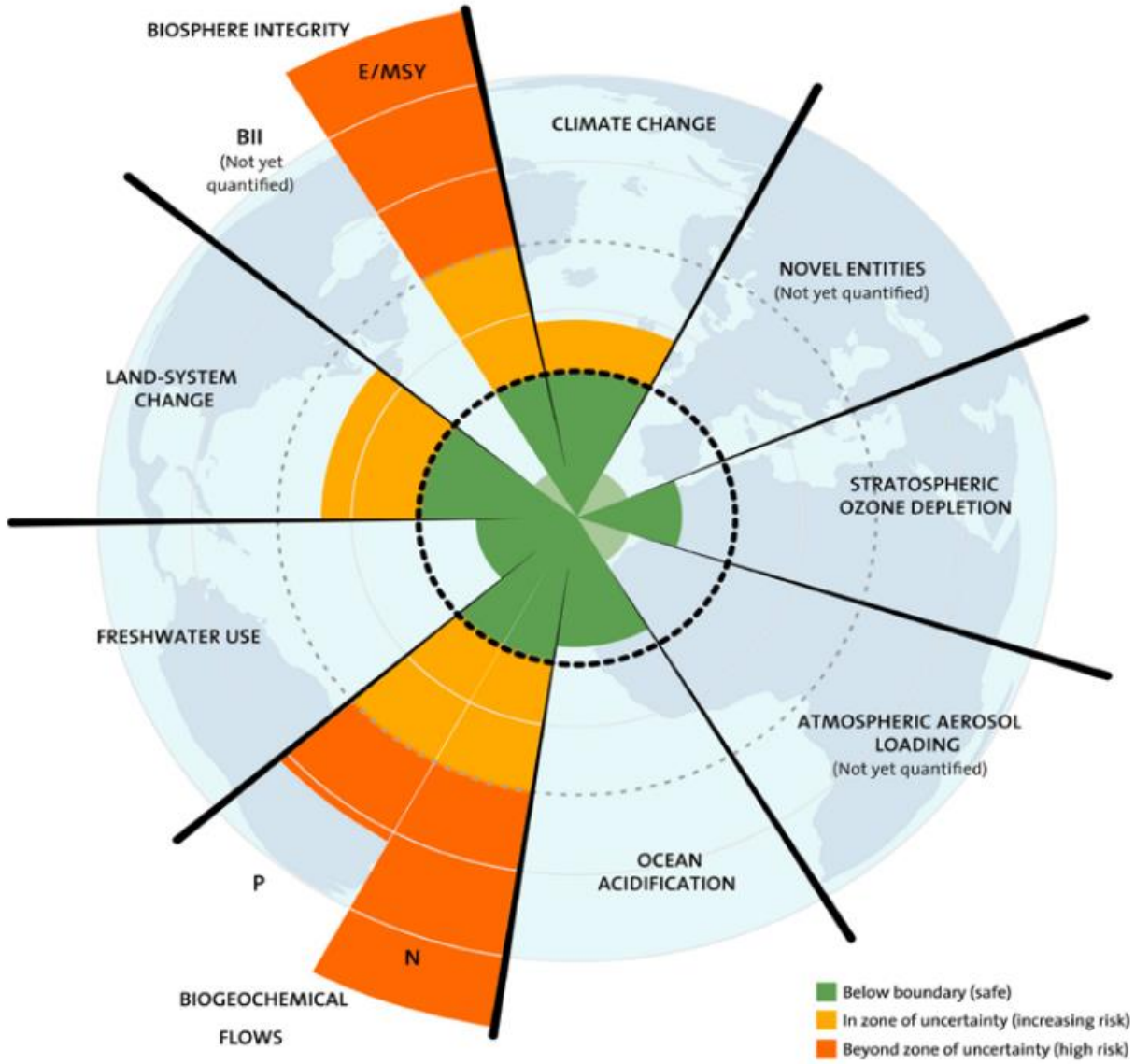
Our W in D

Table | Line | Bar



Planetary Boundaries Source Dasgupta R.

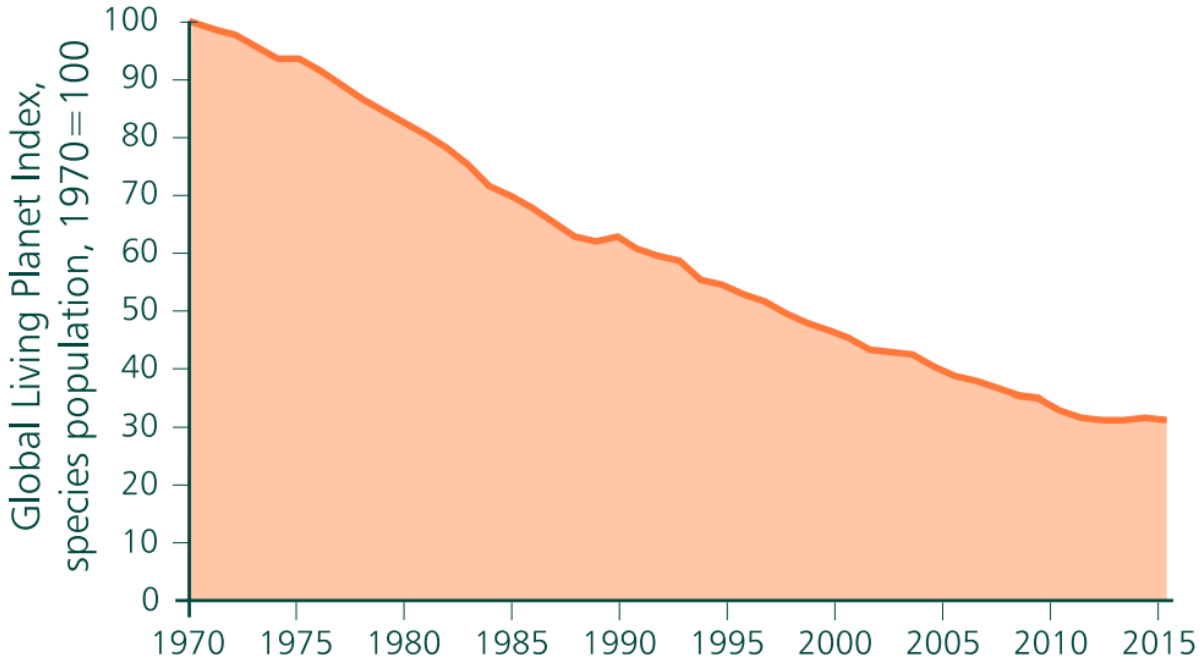
Figure 4.5 Critical Earth System Processes and their Boundaries



Source: Lokrantz/Azote based on Steffen et al. (2015). Note: P = phosphorus; N = nitrogen; BII = Biodiversity Intactness Index and E/MSY = extinctions per million species per year.

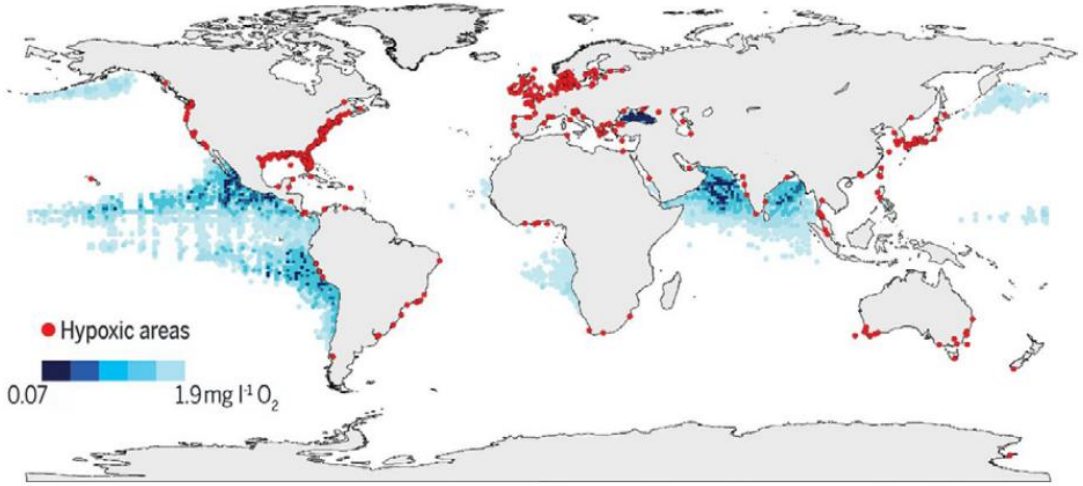
From the Dasgupta Review

Figure A2.3.1 Trends in Global Vertebrate Abundance as Measured by the LPI



Source: WWF/ZS

Figure 4.6 Low and Declining Oxygen Levels in Ocean and Coastal Waters



Source: Breitburg et al. (2018). *Permission to reproduce from The American Association for the Advancement of Science (AAAS).*
Note: Map created from data provided by R. Diaz, updated by members of the GO2NE network, and downloaded from the World Ocean Atlas 2009.

Partha Dasgupta ”On Natural Capital” 2026

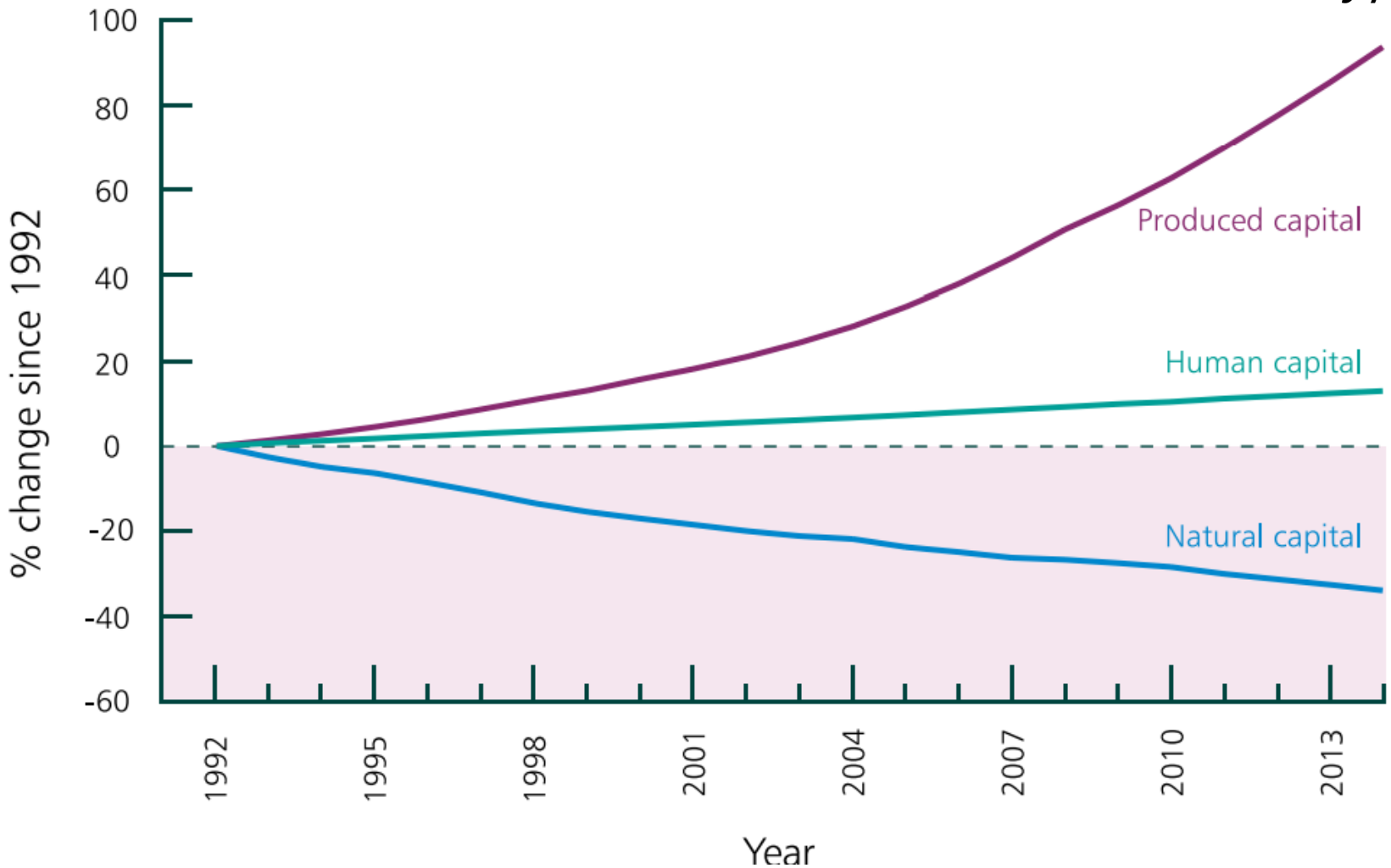
The character of the global economy can thus be pictured on a coin, one side displaying skyscrapers, factories, plantations, agricultural fields, animal farms, and highways in all parts of the world; the other side depicting shrunken lakes, dead oceanic zones, desiccated forests, bleached coral reefs, and infertile watersheds.

Global Wealth per capita

Formally, there is ecological overreach

If $Ny/\alpha > G$

Figure 4.8 Global Wealth Per Capita, 1992 to 2014

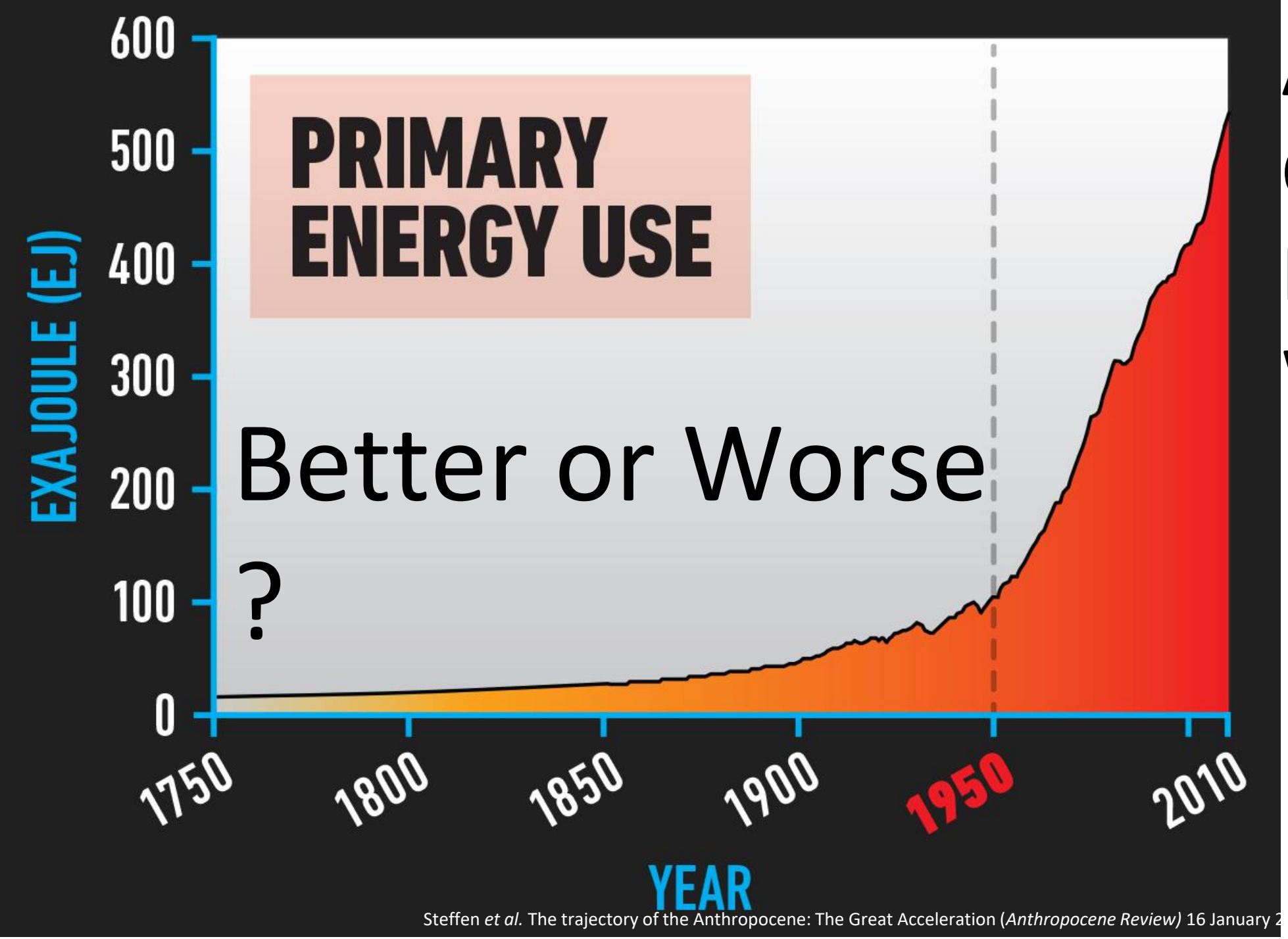


Envisioning a future with climate change

Brian C. O'Neill

Nature Climate Change **13**, 874–876 (2023) | Cite this article

Large segments of the population in high-income countries believe that climate change could lead to the **extinction** of humankind or that, at a minimum, the **future will be worse** than the present. This belief is partly based on projections from climate change research; for example, hundreds of thousands of deaths from heatwaves and other climate-related causes, billions of people at risk of disease, steeply rising damages from floods, millions pushed into poverty, 20% of species going extinct, tipping points about to be bridged and parts of the world already approaching the threshold of a survivable climate[1,2,3]. Statements in the press have echoed, and in some cases magnified, the theme[4,5]. But the very same studies…



Steffen *et al.* The trajectory of the Anthropocene: The Great Acceleration (*Anthropocene Review)* 16 January 2

Also GDP, CO2, CH4, Population Water Dams Urbanis. Fertilizer Fishing..

For Better or for Worse?

- Rockström et al: Climate, Biodiversity, P, N cycles.. Also Bees, bats, Sperm, plastic in the Ocean, coral reefs, Baobab trees
- Rossling: Everything much better that we think: Life expectancy

- PLEASE VOTE

You might be wondering what I think ?

Better AND worse.

Externality Shifting

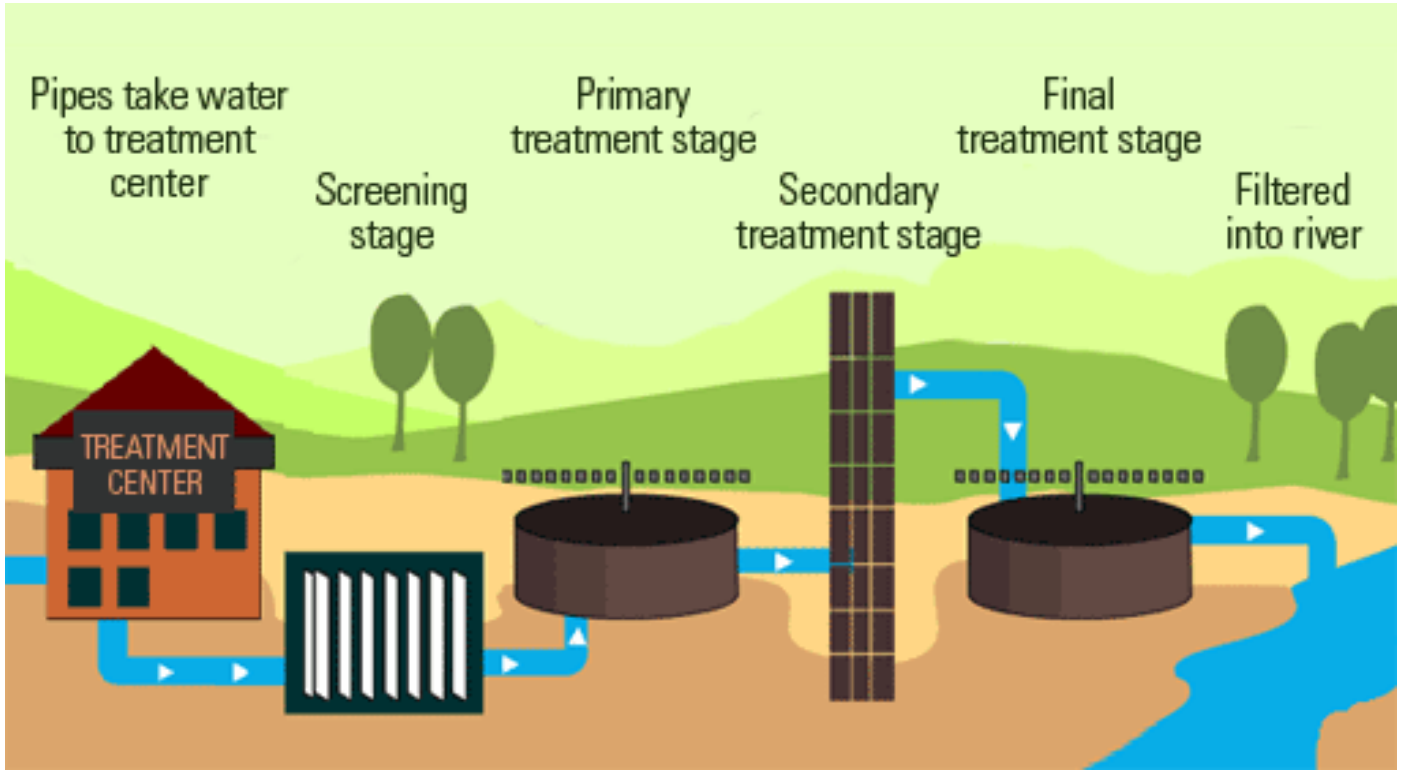
We solve local by creating global problems

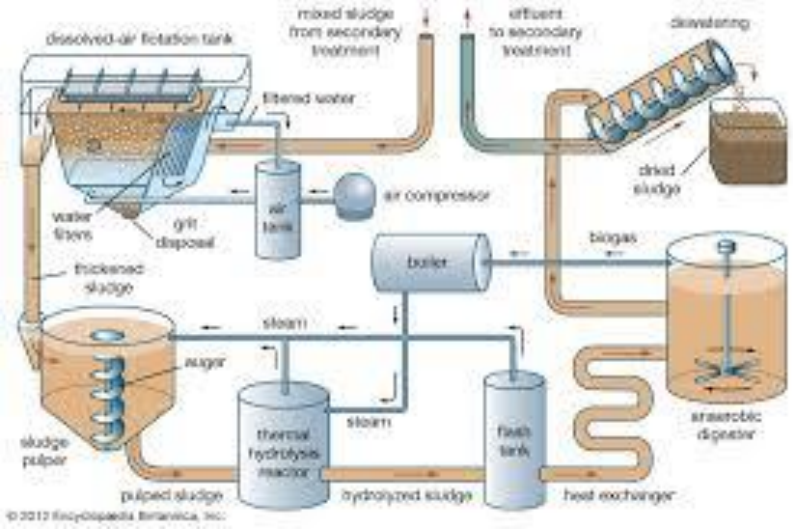
Wash YOUR HANDS!

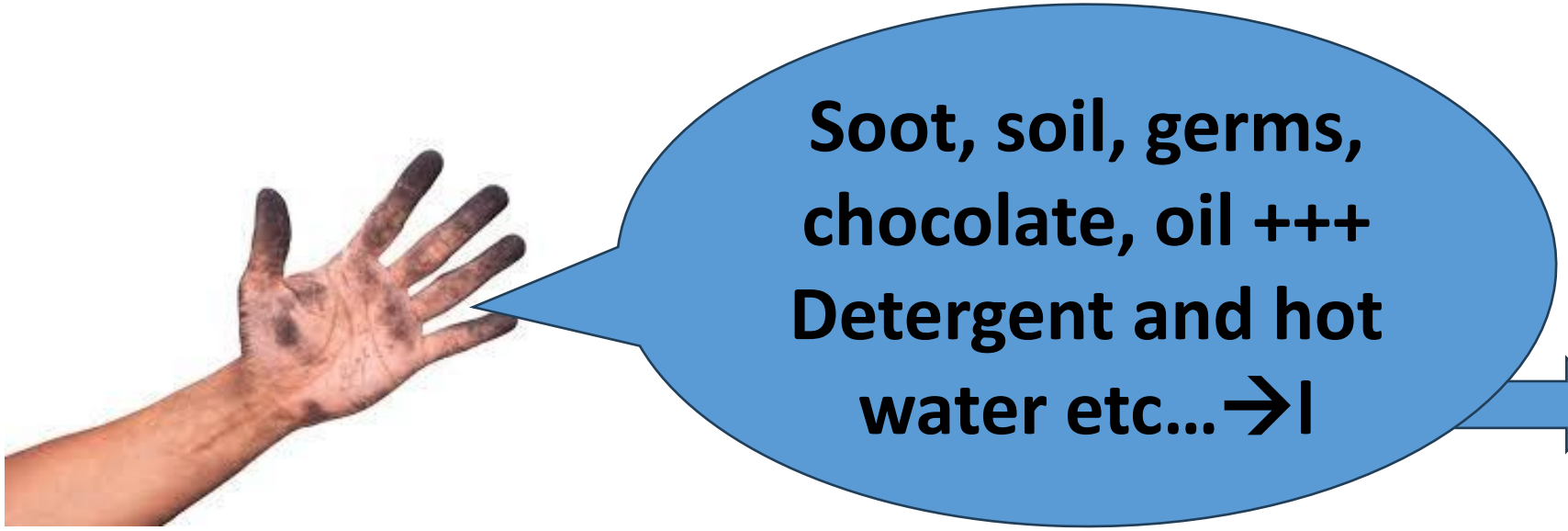
Hands that look clean can still have icky germs!

www.cdc.gov/handwashing

CDC


Pipes take water to treatment center
Screening stage
Primary treatment stage
Secondary treatment stage
Final treatment stage
Filtered into river
TREATMENT CENTER


dissolved-air flotation tank
mixed sludge from secondary treatment
effluent to secondary treatment
dewatering
filtered water
dried sludge
air compressor
water filters
grit disposal
air tank
boiler
biogas
thickened sludge
steam
auger
sludge pulper
thermal hydrolysis reactor
steam
flash tank
anaerobic digester
pulped sludge
hydrolyzed sludge
heat exchanger

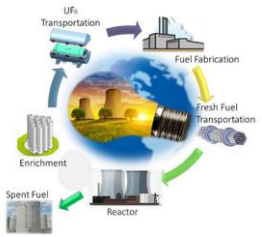

Soot, soil, germs, chocolate, oil +++
Detergent and hot water etc…→I

Waste dump→”energy recovery” incineration

What do you do with all the filters?

Cooking

Heat and Power



Industry

OECD Guidelines to Reduce Emissions of Sulphur Oxides Encouraging the confinement of high polluting fuels to large installations.

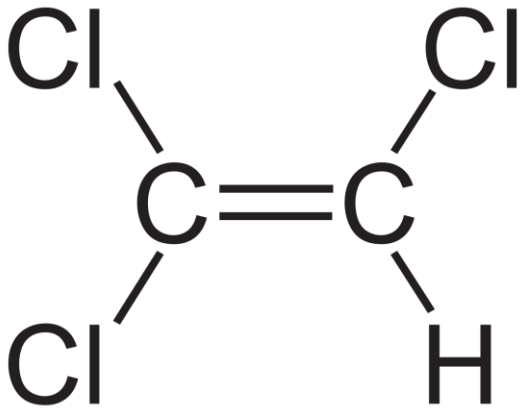
Ensuring these are equipped with tall chimneys and, where necessary, advanced particulate arrestment.

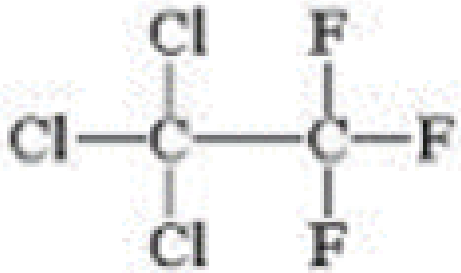
Transport

NY 200 000 horses → 2000 tons manure/d

Solutions imply new problems

Externality shifting takes many forms. **CHEMICALS**

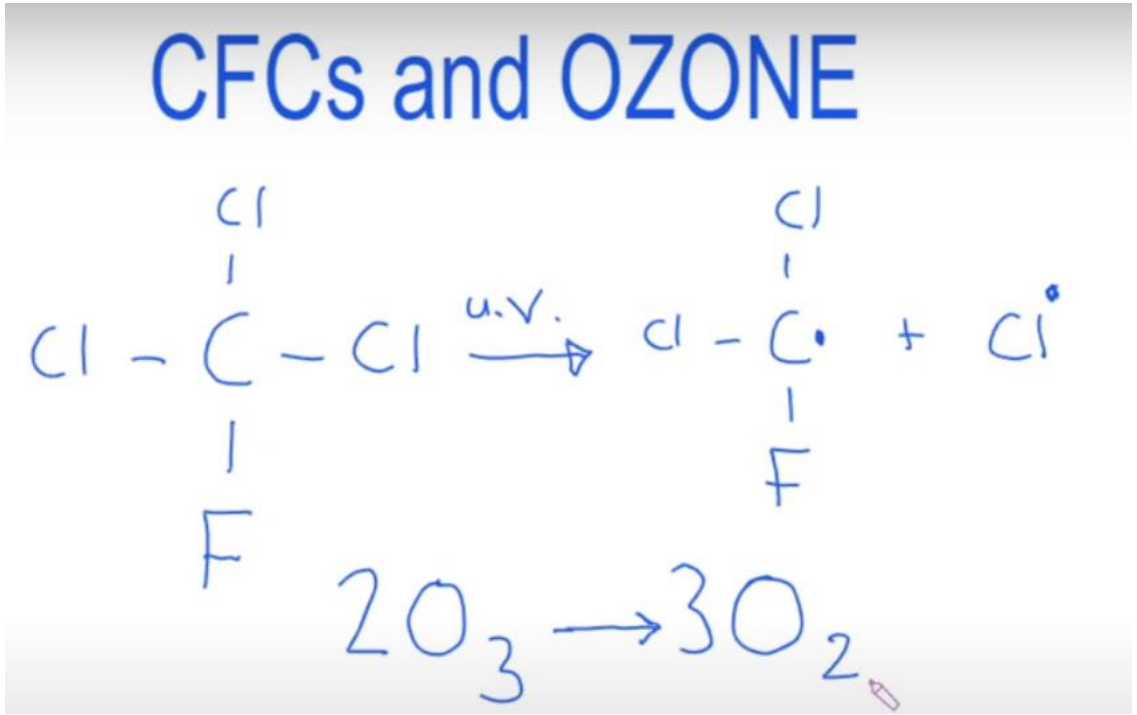




CFC-113

Trichlorofluormethane

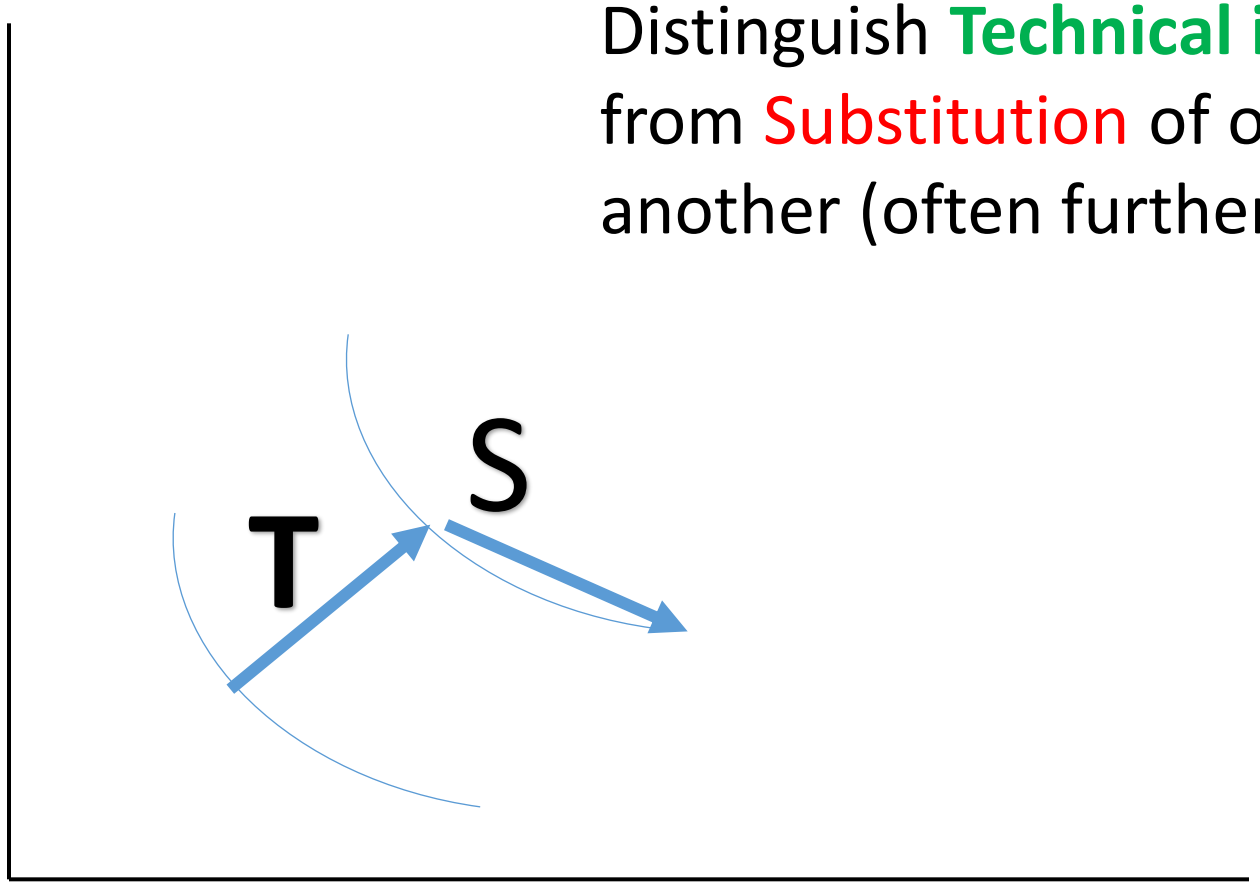
- Stop TCE to reduce human exposure



Another example: Local Pollution related to wear and tear or wind power stations can be fixed using PFAS in paints…

Move environmental liabilities in time & Space

Distinguish **Technical improvement** from Substitution of one problem for another (often further away)



Directed (classical) shifting. Our problems → not global but specific other sites

Modelling Shift: Local → global Now → Future

Firm chooses **Abatement** a_t and **Ext. Shifting** h_t .

- **Total emissions after abatement are** $E_t = \bar{E} - a_t$ (1)

. Abatement cost: $C(a_t)$, with $C' > 0$ and $C'' > 0$

. Shifting cost: $K(h_t)$, with $K' > 0$ and typically $K'' \geq 0$

Share of emissions locally deposited is $\phi(h_t)$,

* **Local (flow) externality** $x_t = \phi(h_t) \cdot (\bar{E} - a_t)$ (2)

- **Addition to global stock pollutant** $y_t = [1 - \phi(h_t)] \cdot E_t$ (3)

Shifting: h_t reduces x_t but increases y_t

- **The global pollutant stock $S_{t+1} = (1 - \delta) \cdot S_t + y_t,$** (4)
- **Local damages from exposure: $D(x_t)$, with $D'(\cdot) > 0$**
- Global damages $G(S_t)$, with $G' > 0$
- Some Local policy, $\tau_t > 0$ No (or weak global $\rho_t \sim 0$)
- Local tax payment $= \tau_t \cdot x_t = \tau_t \cdot \phi(h_t) \cdot E_t$ (5)
  Global tax payment $= \rho_t \cdot y_t = \rho_t \cdot [1 - \phi(h_t)] \cdot E_t$ (6)

Where $0 \leq \rho_t \ll \tau_t$

Firm behavior

Minimizes cost $C(a_t) + K(h_t) + \tau_t \cdot \phi(h_t) \cdot E_t + \rho_t \cdot [1-\phi(h_t)] \cdot E_t$ (7)

- **FOC for abatement** $C'(a_t) = \rho_t + (\tau_t - \rho_t) \cdot \phi(h_t)$ (8)
- If global policy is weak (ρ_t small), abatement incentive come mainly from **local policy**
- If the firm increases h_t (reducing ϕ), it reduces visibility of E_t and reduces incentives to abate.

- **FOC for shifting/dispersion (h_t)** $K'(h_t) = -(\tau_t - \rho_t) \cdot E_t \cdot \phi'(h_t)$ (9)

- Since $\phi'(h_t) < 0$:
- If $\tau_t > \rho_t$ (local policy stronger), the firm chooses higher $h_t \rightarrow$ **more shifting**.

If emissions are priced locally >> globally, Firms will shift rather than abate

Firm behavior if $\rho_t = 0$

Minimizes cost $C(a_t) + K(h_t) + \tau_t \cdot \phi(h_t) \cdot E_t$ (7)

- **FOC for shifting** $K'(h_t) = -(\tau_t) \cdot E_t \cdot \phi'(h_t)$ (8)
- Higher tax τ_t → Higher h_t → **more shifting**

- **FOC for abatement** $C'(a_t) = (\tau_t) \cdot \phi(h_t)$ (9)
- If 80% goes up chimney then abatement incentive is weakened to $C' = 0.2\,\tau$
- Increasing h_t (reducing ϕ), →**reduces incentives to abate**.

Global OPTIMUM

- **Planner chooses $\{a_t, h_t\}$ to minimize discounted social cost:**
- **Minimize $\Sigma_t \beta^t \cdot [\, C(a_t) + K(h_t) + D(x_t) + G(S_t)\,]$**
  Let λ_t be the (discounted) shadow cost of S_t. Then:
- $\lambda_t = G'(S_t) + \beta \cdot (1 - \delta) \cdot \lambda_{t+1}$
- **Define the marginal social cost of global inflow y_t: $m_t \equiv \beta \cdot \lambda_{t+1}$**
- **FOC for abatement and shifting**
- $C'(a_t) = \phi(h_t) \cdot D'(x_t) + [1 - \phi(h_t)] \cdot m_t$
- $K'(h_t) = - E_t \cdot \phi'(h_t) \cdot [\, D'(x_t) - m_t\,]$
- **Note that even in Optimum there may be shifting! Shifting is socially desirable iff local damages D') are high and global damages (global m) low.**

First Best Instruments

- ***Comparing FOC for firm and Soc Planner gives optimal instruments***
- $\tau_t = D'(x_t)$
- $\rho_t = m_t = \beta \cdot \lambda_{t+1}$
- **Global tax can also be written as the present-value expression:**
- $\rho_t = \Sigma\, \beta^k \cdot (1 - \delta)^{k-1} \cdot G'(S_{t+k})$
- BUT GLOBAL POLICY UNAVAILABLE

Second Best Local Policy if Global policy absent

- $\tau_t = D'(x_t) + (m_t - \bar{\rho}_t) \cdot [\, (d\, y_t / d\tau_t) / (d\, x_t / d\tau_t) \,]$ **(SB-τ)**
- NET Result is not obvious
- If Abatement dominates and shift is limited then $\tau_t > D'(x_t)$
- If global policy is too weak, the local tax should be higher, because it also reduces y_t via extra abatement.
- **But if SHIFT dominates then a high τ_t is counterproductive globally since it induces more more shifting, raising y_t and global stock S_t.**
- DIFFICULT AND UNCERTAIN: ACCEPTABILITY PROBLEMS MULTIPLY
- **(Or USE 2 instruments. Set Pigouvian local tax $\tau_t = D'(x_t)$ and limit shift.)**

All eyes on Davos…

Please estimate the likely impact (severity) of the following risks over a 2-year and 10-year period.

Source: World Economic Forum Global Risks Perception Survey 2025-2026.

- THANK YOU

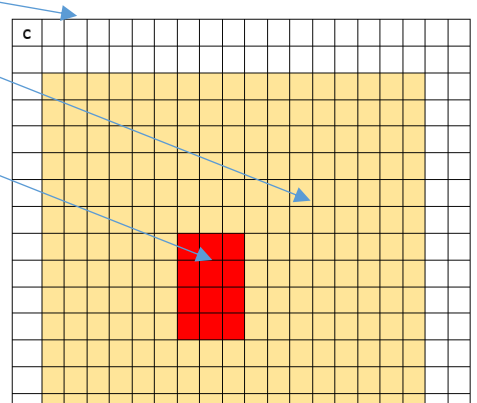
Shifting from externalities to public bads

Define individuals i = {1……n} that together form a set of individuals or a community Ω

Define a subset of individuals Λ_i are the immediate neighbours of i and

Define a second subset which is much larger and includes more distant neighbours Γ_i .

$\Lambda_i \subset \Gamma_i \subset \Omega$



Externality shifting ES

Short distance Externality $U_j = U_j (x_j, x_i)$ if $j \in \Lambda_i$

Long distance Externality $U_j = U_j (x_j, x_i)$ if $j \in \Gamma_i$

Public good (bad) $U_j = U_j (x_j, x_i)$ if $j \in \Omega$

ES is transforming Short dist. Ext → Long dist. Ext → Public bad

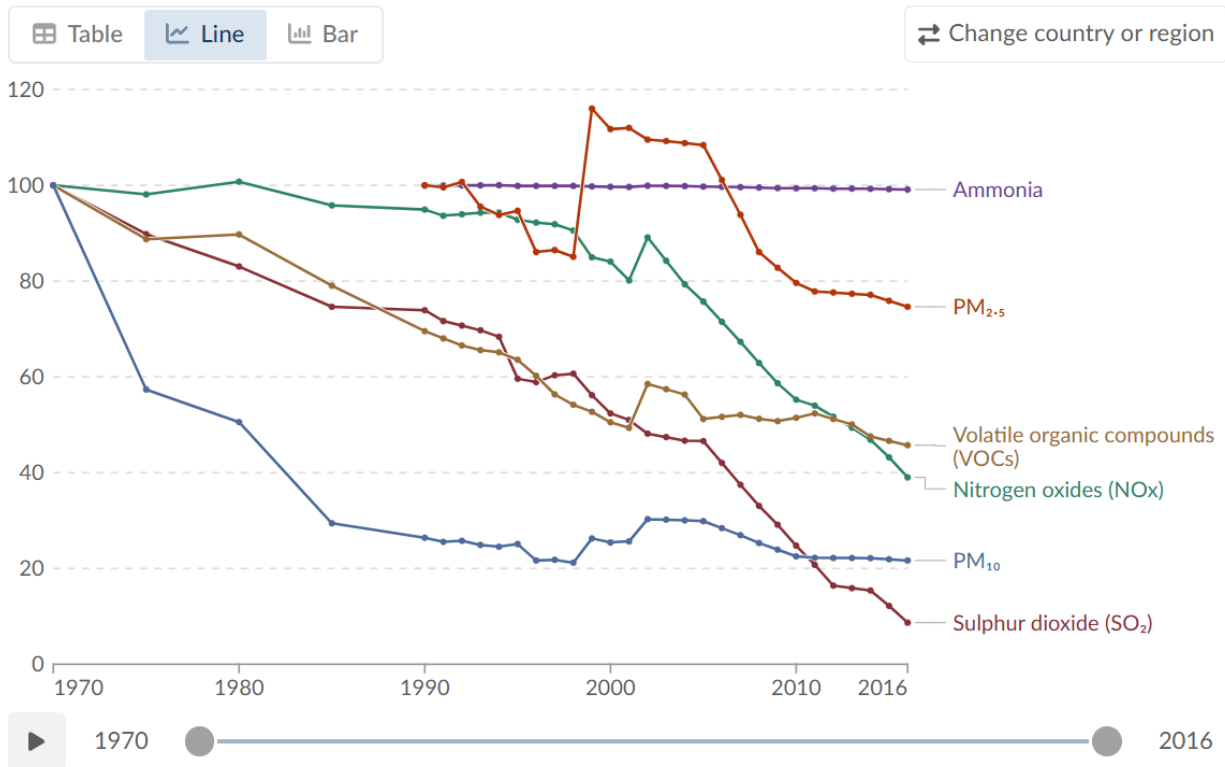
Externality shifting takes many forms and relates PB

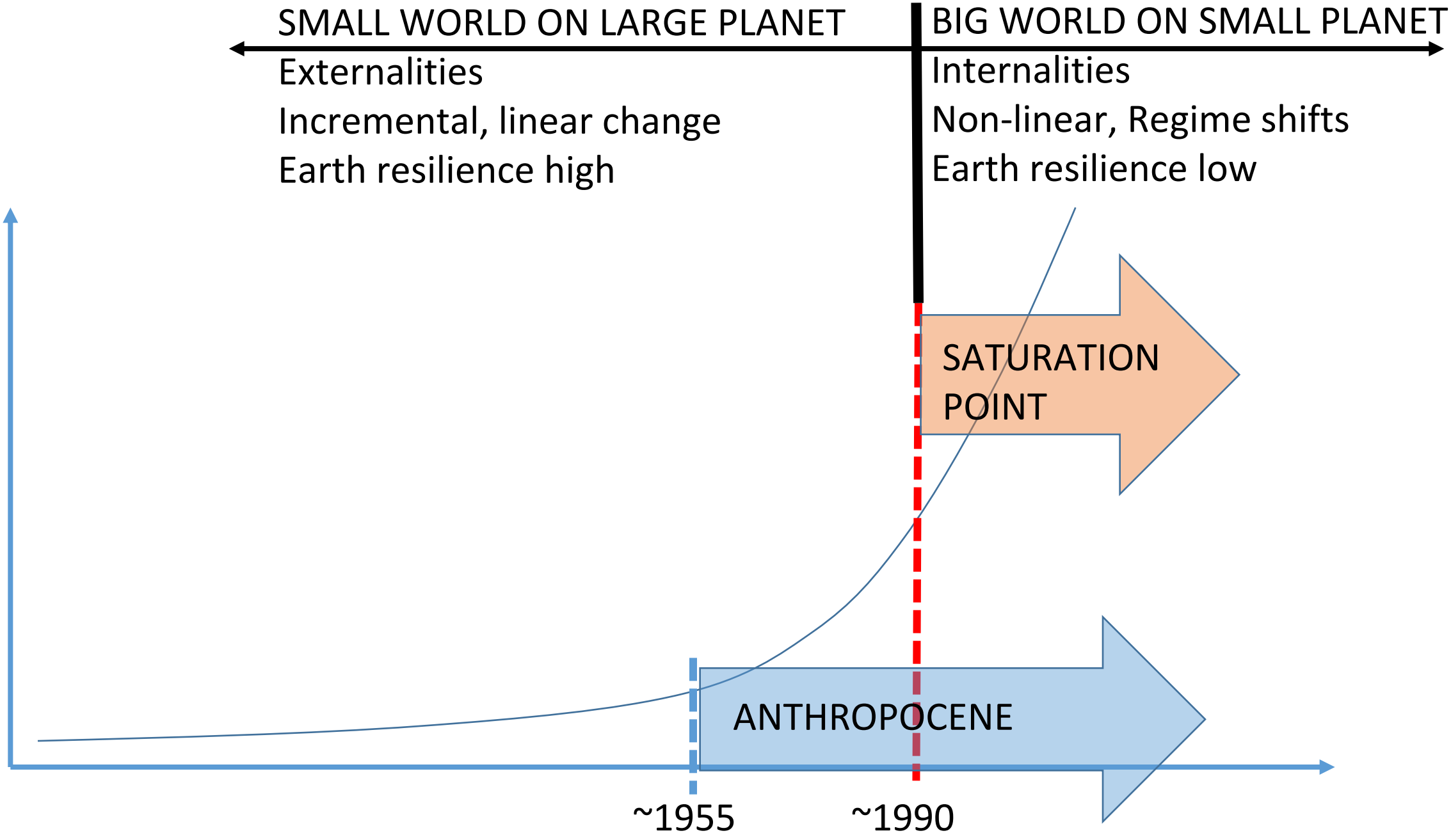
- Washing bodies or cleaning houses
- Chimeneys/smokestacks on houses and factories
- Filters on Chimeneys (where do you put the filters ?)
- Banning landfills → incinerating waste
- Getting rid of TCE and using Freons
- Getting rid of Freons and using HCFCs
- Energy Ladder burning Wood →keroesene ..→ ”clean” Electricty
- Ending up with Nuclear power and Climate change
- Remove heavy chores and bacteria risks by using plastics → Hormone disturbances in fish
- Sulfur and scrubbers in ships, see recent in Reneables

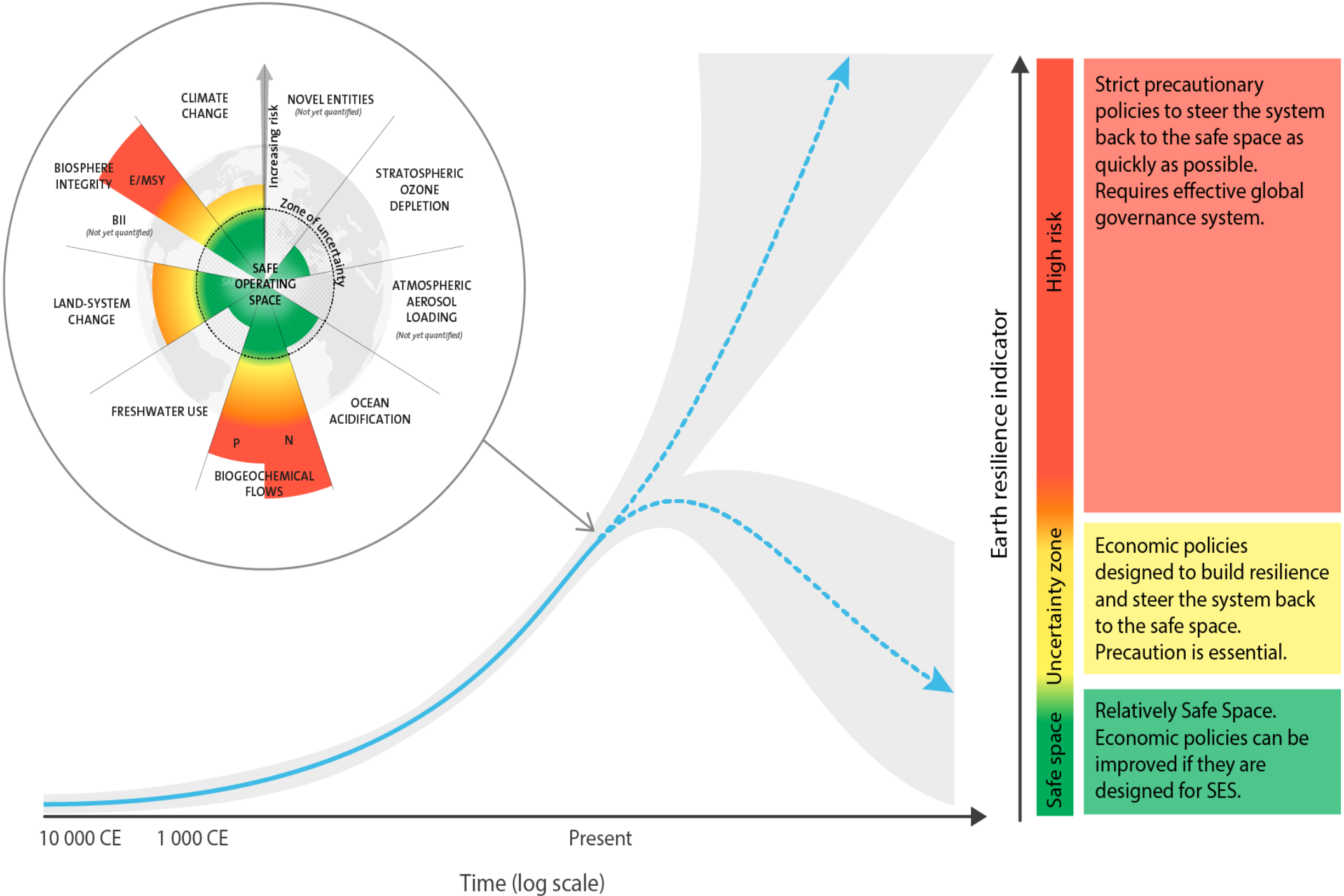
Emissions of air pollutants, United States, 1970 to 2016

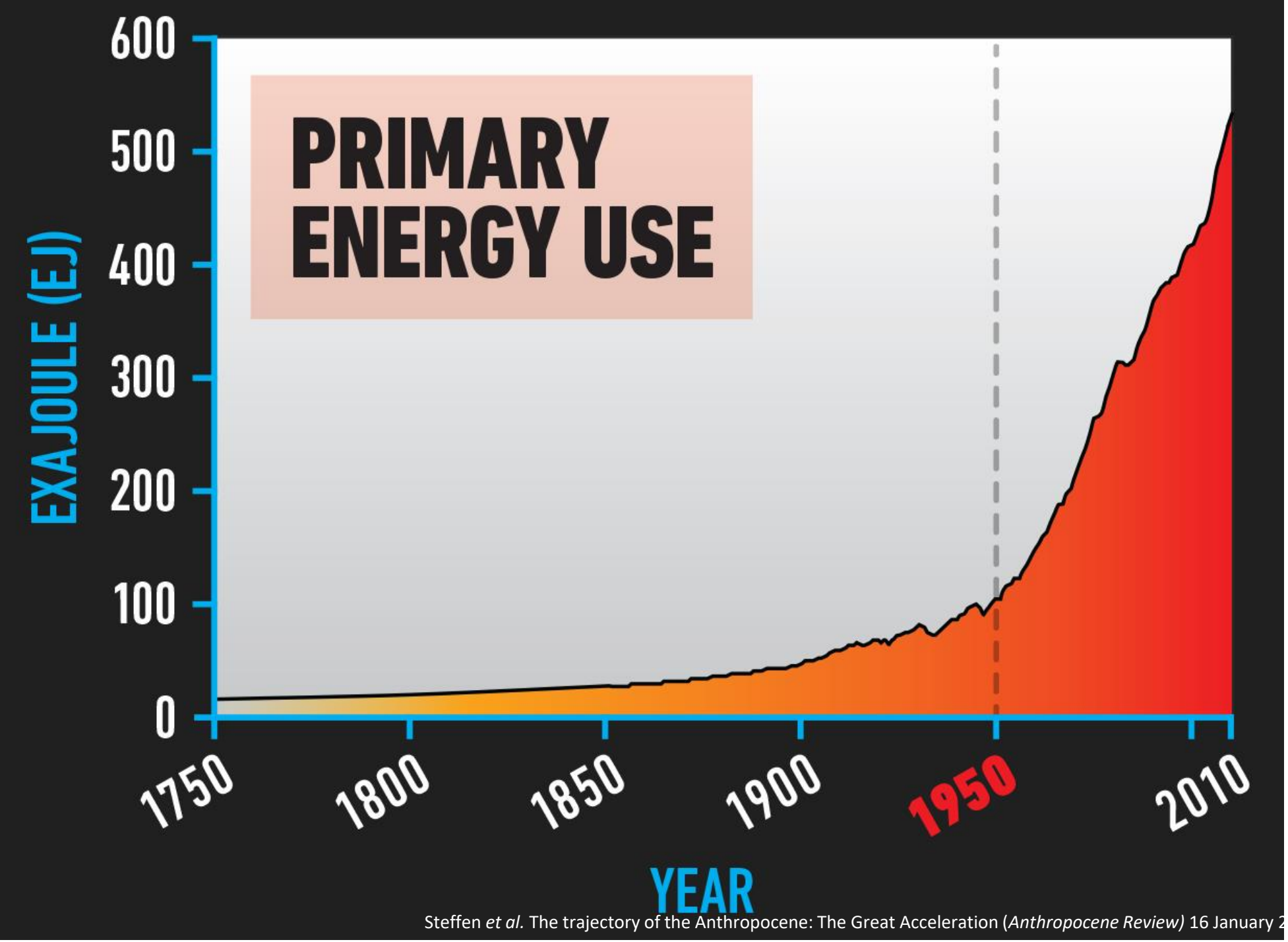
Our World in Data

Annual emissions of various air pollutants, indexed to emission levels in the first year of data. Values in 1970 or 1990 are normalised to 100; values below 100 therefore indicate a decline in emissions. Volatile organic compounds (VOCs) do not include methane emissions.

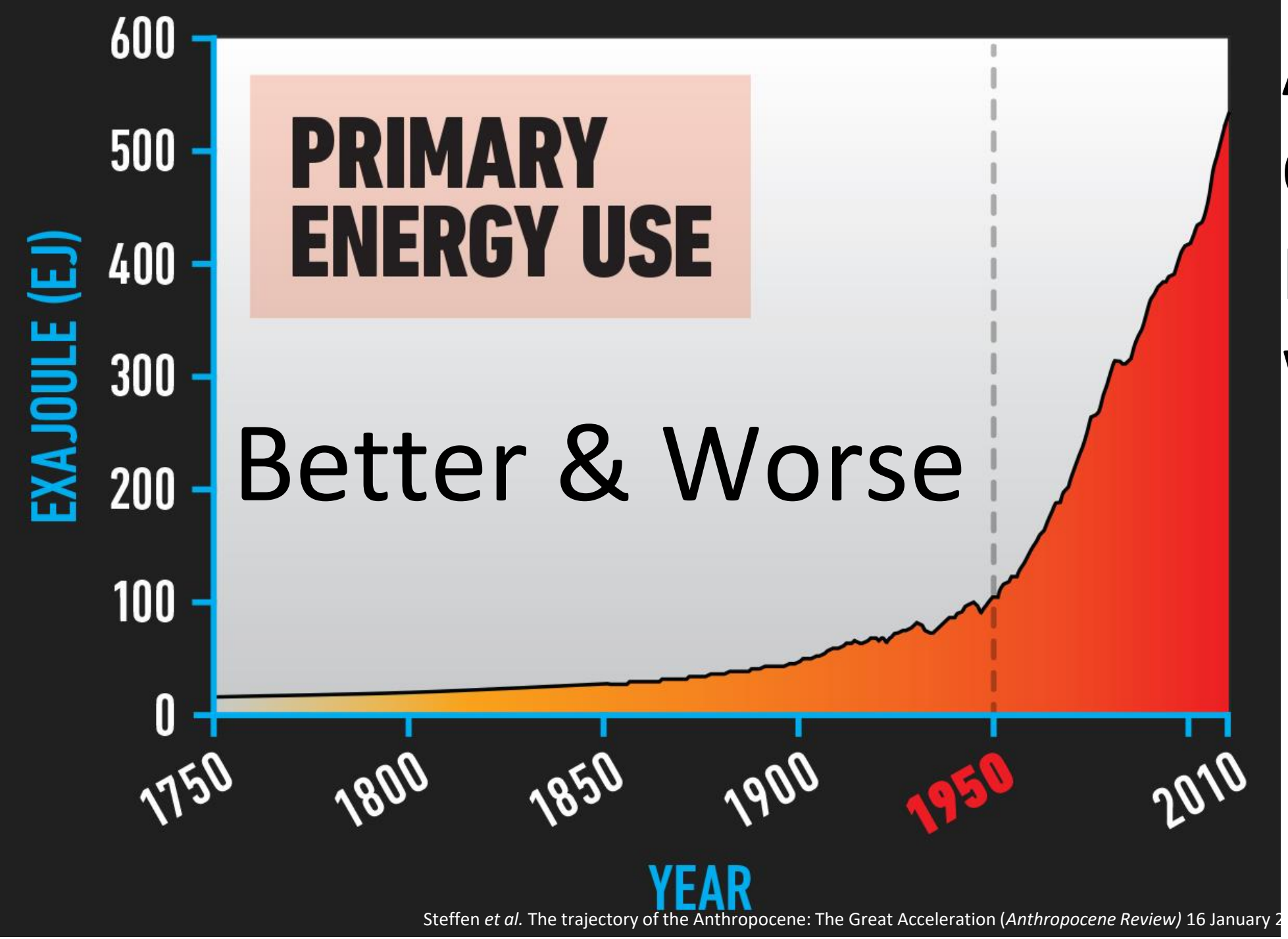



SMALL WORLD ON LARGE PLANET
BIG WORLD ON SMALL PLANET
Externalities
Incremental, linear change
Earth resilience high
Internalities
Non-linear, Regime shifts
Earth resilience low
SATURATION POINT
ANTHROPOCENE
~1955
~1990


CLIMATE CHANGE
NOVEL ENTITIES
(Not yet quantified)
Increasing risk
BIOSPHERE INTEGRITY
E/MSY
BII
(Not yet quantified)
STRATOSPHERIC OZONE DEPLETION
Zone of uncertainty
SAFE OPERATING SPACE
ATMOSPHERIC AEROSOL LOADING
(Not yet quantified)
LAND-SYSTEM CHANGE
FRESHWATER USE
OCEAN ACIDIFICATION
P
N
BIOGEOCHEMICAL FLOWS
Earth resilience indicator
High risk
Uncertainty zone
Safe space
Strict precautionary policies to steer the system back to the safe space as quickly as possible. Requires effective global governance system.
Economic policies designed to build resilience and steer the system back to the safe space. Precaution is essential.
Relatively Safe Space. Economic policies can be improved if they are designed for SES.
10 000 CE
1 000 CE
Present
Time (log scale)



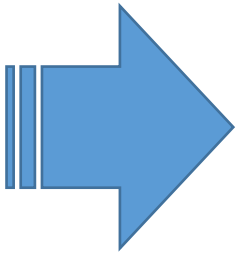
Steffen *et al.* The trajectory of the Anthropocene: The Great Acceleration (*Anthropocene Review)* 16 January 2



Steffen *et al.* The trajectory of the Anthropocene: The Great Acceleration (*Anthropocene Review)* 16 January 2

Also GDP, CO2, CH4, Population Water Dams Urbanis. Fertilizer Fishing..

Both better ---- and worse



Modelling Shift: Local → global Now → Future

Firm chooses **Abatement** a_t and **Externality Shifting** h_t . (Figuratively, h can be seen as chimney height or pollution dispersion)

- **Total emissions after abatement are** $E_t = \bar{E} - a_t$ (1)

. Abatement cost: $C(a_t)$, with $C' > 0$ and $C'' > 0$

. Shifting cost: $K(h_t)$, with $K' > 0$ and typically $K'' \geq 0$

Share of emissions locally deposited is $\phi(h_t)$, [$0 < \phi(h_t) \leq 1$ and $\phi'(h_t) < 0$]

- **The local (flow) externality is** $x_t = \phi(h_t) \cdot E_t$ (2)
- **Annual addition to global stock pollutant** $y_t = [1 - \phi(h_t)] \cdot E_t$ (3)

The shift function h_t reduces x_t but increases y_t

- **The global pollutant stock $S_{t+1} = (1 - \delta) \cdot S_t + y_t$,** (4)
- Global damages $G(S_t)$, with $G' > 0$ (often convex)
- Assume policy instruments, locally $\tau_t > 0$ and weaker ρ_t globally
- Local tax payment = $\tau_t \cdot x_t = \tau_t \cdot \phi(h_t) \cdot E_t$ (5)
  Global tax payment = $\rho_t \cdot y_t = \rho_t \cdot [1 - \phi(h_t)] \cdot E_t$ (6)

Where $0 \leq \rho_t \ll \tau_t$

Firm behavior

Minimizes cost $C(a_t) + K(h_t) + \tau_t \cdot \phi(h_t) \cdot E_t + \rho_t \cdot [1 - \phi(h_t)] \cdot E_t$ (7)

- **FOC for abatement** $C'(a_t) = \rho_t + (\tau_t - \rho_t) \cdot \phi(h_t)$ (8)
- If global policy is weak (ρ_t small), abatement incentive come mainly from **local policy**
- If the firm increases h_t (reducing ϕ), it reduces visibility of E_t and reduces incentives to abate.

- **FOC for shifting/dispersion (h_t)** $K'(h_t) = -(\tau_t - \rho_t) \cdot E_t \cdot \phi'(h_t)$ (9)

- Since $\phi'(h_t) < 0$:
- If $\tau_t > \rho_t$ (local policy stronger), the firm chooses higher $h_t \rightarrow$ **more shifting**.

If emissions are priced locally >> globally, Firms will shift rather than abate

The great acceleration and the global food system

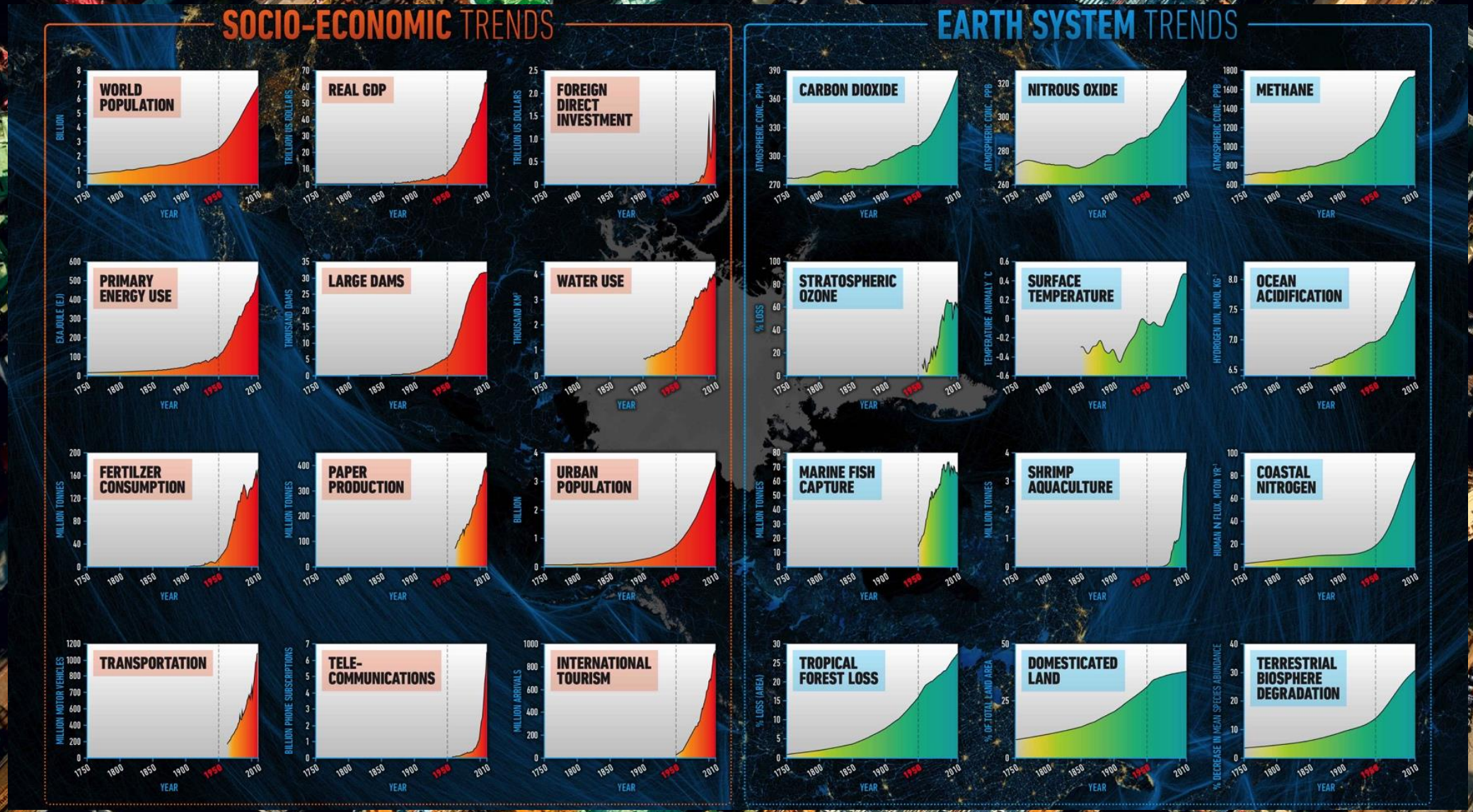


Image: GLOBAIA

Classical Externality shift – a special case
Neighbours trash smell bad? Push it downhill