The Anthropocene: humans lock-in with fossil fuels, and their lock-out

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A sociometabolic reading of the Anthropocene: Modes of subsistence, population size and human impact on Earth.
Anthropocene Review 1, 8-33.
what I will talk about

1. The grand socio-metabolic regimes of human history and how they mold our impact upon Earth
2. Population dynamics
3. Human affluence as energy affluence
4. Technology as mitigating or aggravating impacts
5. Some better news for the 21st century
Anthropocene: Humans becoming a planetary force – when, and why?

- By the transition from humans as hunters & gatherers to humans as agriculturalists, starting some 12000 years ago (Kaplan et al. 2009, Ruddiman 2003)
- By the industrial transformation in the latter part of the 18th century (Crutzen & Stoermer 2000)
- By the 'Great Accelleration' after World War II (Steffen et al. 2007)
  Marker: radionuclides in tree-rings (Lewis & Maslin 2015, Steffen 2014)
- We think the dividing line is the use of fossil fuels, starting with the 16th century.
1. The grand socio-metabolic regimes in human history

- **Hunters and Gatherers**: passive solar energy use
- **Agrarian societies**: active solar energy use – land cover change, deforestation
- **Industrial societies**: fossil energy use – change in global biogeochemical cycles

**Neolithic transition**

**Fossil fuel transition**

**Sustainability transition?**

Source: adapted from Sieferle et al. 2006
What makes humans a planetary force?
> It is the size of their impact upon nature

- This impact (or rather: the anthropogenic pressure) can be approximated by the classical IPAT formula (Ehrlich 1968).
  - $I = \text{environmental impact (pressure)}$
  - $P = \text{size of the human population}$
  - $A = \text{affluence per capita}$
  - $T = \text{technology coefficient per unit affluence}$

- But: the human population at each point in time is not homogenous: each mode of subsistence (sociometabolic regime) has its own profile, extension and dynamics

$$I_t = (P_{t1} \times A_{t1} \times T_{t1}) + (P_{t2} \times A_{t2} \times T_{t2}) + (P_{t3} \times A_{t3} \times T_{t3})$$
Steps towards arriving at quantitative estimates and solving the equation

1. Achieve a deeper qualitative understanding of the functioning of the three sociometabolic regimes and their dynamics across time

2. Generate from existing global population estimates a plausible subdivision of populations by regimes across time

3. Generate a measure of „affluence“ for each regime across time. Our choice: use energy affluence as an indicator that is environmentally relevant and can be estimated

4. Describe the technology by which this affluence is generated and used in a quantifyable way. Our choice: use carbon emissions per unit energy (as related to climate change)
## 1. Sociometabolic regimes and their dynamics

<table>
<thead>
<tr>
<th></th>
<th>Hunters &amp; Gatherers</th>
<th>Agrarian</th>
<th>Industrial</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Population</strong></td>
<td>low fertility, low growth, low population density, migratory, low labor burden</td>
<td>high fertility, high growth, urban centres emerge, sedentary, high labor burden</td>
<td>very low fertility, high life expectancy, neg. growth, rapid urban growth, wage labor + education</td>
</tr>
<tr>
<td><strong>Affluence / Energy Use (DEC)</strong></td>
<td>passive solar energy use, food + firewood</td>
<td>active solar energy use, + feed for dom. animals, construction and mining, affluence dep. on territory</td>
<td>+ fossil fuel use, + increase in domesticated animals</td>
</tr>
<tr>
<td><strong>Technology with ref. to carbon emissions</strong></td>
<td>food prep. with woodfire, ev. use of fire in hunting, hardly tech. development, fairly carbon neutral</td>
<td>transformation of forests to cropland and grassland, soil loss, slow tech. development</td>
<td>fossil fuel combustion, fossil based intensification of agriculture, reforestation, fast tech. development</td>
</tr>
<tr>
<td><strong>Interactions</strong></td>
<td><em>pop growth &gt; labor intensification &gt; fertility &gt; pop growth (Boserup)</em>, <em>affluence declining</em></td>
<td><em>outcompete hunters &amp; gatherers</em></td>
<td><em>energy affluence &gt; tech.dev &gt; econ.growth &gt; tech dev (Ayres)</em>, <em>wage labor + tech.dev &gt; low fertility &amp; mortality &gt; pop decline</em></td>
</tr>
</tbody>
</table>
2. How to arrive at population estimates for hunter&gatherers and agrarian population

• **demographic estimate:**
  Before 10,000 BC, the whole human world population were hunters and gatherers; their population grows slowly; at an assumed plausible growth rate of 0.036 annually, they arrive at ± 90 millions in AD 1. The remaining world population should already be agrarian.

• **sociometabolic estimate as cross-check:**
  a) when urban centres emerge, there must be an agrarian population.
  b) in the early phases, it takes about 98 peasants to feed 2 urban citizens; later this relation shifts to 96.5 : 3.5.

  Using this assumption and the existing estimates of urban population, we generated an independent estimate of agrarian population. We arrive at very similar numbers.

• A dominance of agrarian population drives hunter&gatherers into decline; they become largely extinct by 1500 AD.
How to arrive at estimates distinguishing between agrarian and industrial populations

- Modern classifications of „industrial countries“ don‘t reach back in history so far, and they do not capture internal differences (e.g. industrialized cities and agrarian hinterland). How could we proceed?
- We assume urban populations beyond 3-4% (in extreme cases: 10%) cannot be sustained by traditional farming
- We can demonstrate for many countries that urban growth beyond this ratio is directly linked to fossil fuel (peat, coal…) use. Globally, there is a linear relation between fossil fuel use and the size of urban population.
UK‘s urban population takeoff 1500-1800 AD

Index: Urban population
1500 AD = 1
Global urban population and global modern energy (fossil fuels ...) use (data points 1500 – 2000 AD)
How to arrive at estimates distinguishing between agrarian and industrial populations

• Solution: beyond the traditional marginal urban population, we equate „industrial population“ with urban population.
Global population dynamics 10,000 BC- 2000 AD by modes of subsistence

a) Hunter gatherers and agrarian population (0-1500 AD)

b) Rise of the industrial population (1500-2000 AD)
Global population dynamics 10 000 BC- 2000 AD
by modes of subsistence (shares)
3. As environmentally relevant and long-term comparable measure of „affluence“ we use energy affluence (DEC/capita)

- DEC contains commercial energy (as measured by TPES, *total primary energy supply*) plus the amount of primary energy input into the endosomatic processes of humans and livestock (food and feed), in calorific units.
  - More recent data were compiled from IEA (TPES) plus biomass from material flow accounts. For historical time periods we rely mainly on Podobnik’s (2011) data on coal extraction and trade, and developed estimates for biomass use based upon historical landuse data and agricultural statistics (harvest, livestock) as well as population statistics (Madison 2006, Krausmann & Haberl 2002)
- We gradually built up a historical database for many countries of the world, controlling it for consistency and comparability (*SEC data base*)

From correlation analysis of more recent times, we can claim that DEC as measure of energy affluence also very well represents the amount of materials that can be used per person. So this indicator also represents society‘s „biophysical affluence“. 
3. Metabolic rates by sociometabolic regime (GJ/cap DEC = primary energy use)
Share of fossil fuels (and other „modern“ energy carriers) in primary energy use (DEC) 1500-2000
Transitions in the share of different modes of subsistence in global energy use (DEC)
Transitions in share of different modes of subsistence in global energy use (DEC)

DEC consists of biomass (including all food for humans, feed for livestock and all biomass used as fuel or raw material) and modern energy carriers such as fossil fuels, nuclear energy and hydroelectric energy. Note: Time axis is not to scale for different periods: -10000 to 0: 1000 year intervals; 0-1900: 100 year intervals; 1950-2010: 10 year intervals.
Available primary fossil fuel (...) energy per capita 1500 - 2000

fossil energy use (GJ/cap/yr-1)

1500 1550 1600 1650 1700 1750 1800 1850 1900 1950 2000
4. Preliminary conclusions from population and affluence – what about technology?

- Human impact on Earth between AD 1 and AD 1500, as derived from population growth and energy affluence, increased 4.8 fold; population growth alone would only have accounted for a 2.4 fold increase.

- From 1500 AD onwards, the increase is much steeper: it more than doubles 1500-1800, from 1700 on it doubles per century, from 1900 on it doubles in 50 years, and from 1950 on it tripled in 50 years.

- Did technology in the long run help to mitigate the impacts from population and affluence? The answer is disconcerting: within sociometabolic regimes it did, but the technology shifts between regimes make things worse.
**IPAT coefficients used for estimates**

<table>
<thead>
<tr>
<th>Population dynamics (annual growth)</th>
<th>Hunters &amp; gatherers</th>
<th>Agrarian regime*</th>
<th>Industrial regime**</th>
</tr>
</thead>
<tbody>
<tr>
<td>0&lt;X&lt; 0.05 turns negative when agr.regime dominates</td>
<td>( X&gt;0.4 ) rises under influence of the industrial regime</td>
<td>( X&lt;0 ) masked by conversions from agrarian regime</td>
<td></td>
</tr>
<tr>
<td>Affluence GJ/cap* a DEC</td>
<td>± 10</td>
<td>± 50</td>
<td>±200</td>
</tr>
<tr>
<td>Technology coefficient*** tC/GJ</td>
<td>0</td>
<td>( X&gt;10 ) higher in the beginnings</td>
<td>13&gt;X&lt;25 higher in the beginnings (coal)</td>
</tr>
</tbody>
</table>

* Agrarian pop size estimated from (known) urban centres (urban = 2%-3,5% of total)
** Industrial population size after 1500 AD equal to global urban population
*** Estimated separately for agriculture (traditional / industrial) and other production
## Human pressure/impact in the past two millennia

<table>
<thead>
<tr>
<th></th>
<th>year Ad 1</th>
<th>year AD 2010</th>
<th>increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>population</td>
<td>190 million</td>
<td>6800 million</td>
<td>36 fold</td>
</tr>
<tr>
<td>energy affluence</td>
<td>40 GJ /cap/ year</td>
<td>120 GJ / cap/year</td>
<td>3 fold</td>
</tr>
<tr>
<td>(DEC)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>carbon intensity</td>
<td>9 t C / GJ</td>
<td>15 t C / GJ</td>
<td>almost 2 fold</td>
</tr>
</tbody>
</table>

Sources: Boden 2013, Houghton 2008, own calculations

150 fold pressure
IPAT: Human pressure/impact due to population numbers, affluence (energy use) and technological carbon emission intensity, AD 1 - 2010

Population increased from 190 – 6800 million, that is 36 fold.

Energy affluence increased from about 40 GJ/person to 120 GJ/person, that is 3 fold.

Carbon intensity rose from about 9tC/GJ to about 15tC/GJ, that is almost 2 fold.
Important by-products of the analysis I: 
16th century – energy transition – urbanity – beginning of modernity

• We show that fossil fuel use starts in the 16th century (peat NL, coal UK). It mainly feeds into urban growth: in the agrarian regime, urban populations had been constrained to 2-5% (exceptionally 10%) of the agrarian population.

• Growing cities generate the cultural climate of rationalism, inventiveness, art and science that supports not only the renaissance, but great technological innovations in the long run.

• A focus on the energy transition towards fossil fuels thus allows to match the beginning of modernity according to social and cultural history with the beginning of the great socioecological transformation, in timing and causality.
5. Some better news for the 21st century

• For the first time, it is projected that human population growth will decline and probably turn negative within this century, from 2050 or 2070 onward (Lutz 2014, Randers 2012)

• Since the early 1970s, per capita energy and material use in mature industrial countries stagnate (Wiedenhofer et al. 2013); However, their level is too high for the rest of the world catching up with it – we need to go for contraction and convergence, and we will not be able to avoid that.

• Finally, humanity has started to learn how to create a good quality of life at lower energy and material standards.
How much energy do we need for a long life?

Steinberger & Roberts 2010 (data update)
Global modern energy use and human development 1975-2005 (by countries)

Yes, we can!

source: Steinberger & Roberts 2009