IEooc_Application1_Exercise2: Quantifying sociometabolic transitions with the IPAT equation

Goal: *Understand how population, affluence, and a cap for a certain emission to the environment determine how industry must decouple from that emission. Learn about and apply the IPAT equation and link it to global climate and development targets.*

Problem setting

Sustainability, at the large scale, is about meeting both environmental and societal goals. Simply speaking, environmental sustainability means putting a cap on certain environmental impacts I, such as greenhouse gas emissions or emissions or particulate matter. Economic development (still) is a major societal goal; it is commonly measured by the personal affluence, that is, the average spending A per person.

The following equation, called IPAT after its four constituents I, P (Population), A, and T (Technology), links the two sustainability goal indicators: the impact I with the affluence A:

$$I = P \cdot A \cdot T$$

$$[\frac{kg}{yr}] = [p] \cdot [\frac{\$}{yr \cdot p}] \cdot [\frac{kg}{\$}]$$

The IPAT equation is an accounting identity. It always holds, as the right side of the equation is simply a different breakdown of total impacts:

$$I = I$$

$$I = GDP \cdot \frac{I}{GDP}$$

$$I = P \cdot \frac{GDP}{P} \cdot \frac{I}{GDP}$$

The equation above always holds for nonzero P and GDP. The term GDP/P is the per capita affluence A, and the term I/GDP is the average environmental impact per economic output T.

In the IPAT framework, emissions have three drivers: The scale of a society, measured by its population, the personal affluence, measured by per capita spending, and the average emissions intensity of the economy, measured by impact per dollar of GDP produced.

One can use the IPAT equation to get an idea of how the change of P, A, and T plays together to determine changes in I over time. In particular, we want to investigate to what extent T, the aggregate emissions intensity of the economy, needs to change compared to historic values.

The example below was adopted from Tim Jackson's "Prosperity without growth" (Jackson, 2009).

Focussing on climate change mitigation, we want to understand the option space for A and T given global and national reduction targets for greenhouse gas emissions I and population scenarios P.

This exercise focusses on the US and China as examples of countries that were industrialized and industrializing in 1990, respectively.

Question:

Is a continuation of the historic development of the coupling between emissions and economic output, expressed by T, sufficient to reach ambitious climate targets in 2050?

Or, more simply: ***If we extrapolate the trend seen in T over the last decades to 2050, will the countries be able to reach their climate targets under reasonable growth assumptions?***

Data

To answer these question, a number of data on P, A, and I for the years 1990 and 2017 (reference period) and for 2050 (scenario benchmarks) are given. Tables 1 and 2 show the data for the US and China for I, P, and A for the reference years 1990, 2017, and 2050:

Table 1: IPAT data for the USA.

USA	1990	2017	2050 base	2050 max	Ref
Population (million)	252.53	324.459	389.592		UN Population Division. World Population Prospects: The 2017 Revision.
GHG emissions (Mt CO2-eq/yr) (I)	6400	6400	3200	640	https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions
PPP-GDP-pC (constant 2011 I$) (A)	34062	54255.4			https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.KD
Red numbers: 50% and 90% reduction					

Table 2: IPAT data for China.

China	1990	2017	2050 base	2050 max	Ref
Population (million)	1172.445	1409.517	1364.457		UN Population Division. World Population Prospects: The 2017 Revision.
GHG emissions (Mt CO2-eq/yr) (I)	3211	11735	11207	2241	https://climateactiontracker.org/countries/china/
PPP-GDP-pC (const. 2011 I$) (A)	1526.4	15308.7			https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.KD
Red numbers: Same per capita emissions as for USA with 50% and 90% reduction rel. to 1990.					

Guidance:

For both countries and for the years 1990 and 2017, the IPAT equation can be formulated and used to calculate T. One can then determine the average annual change rate of T for both countries.

For 2050, we need an economic growth scenario. Simply extrapolating historic growth rates could work for the US but probably not for China, which has seen a tenfold increase in purchase power parity (PPP) GDP over the 1990-2017 period.

For comparison purposes, an *annual growth rate of per capita GDP* of 2% for the US and 4% for China shall therefore be assumed for the period 2017-2050. Any other reasonable rates can be used as well.

References:

Link to the IPAT equation on Wikipedia: https://en.wikipedia.org/wiki/I_%3D_PAT

Jackson, T., 2009. Prosperity without growth. Routledge, London.