Recitation: Discussion of Sustainability Issues

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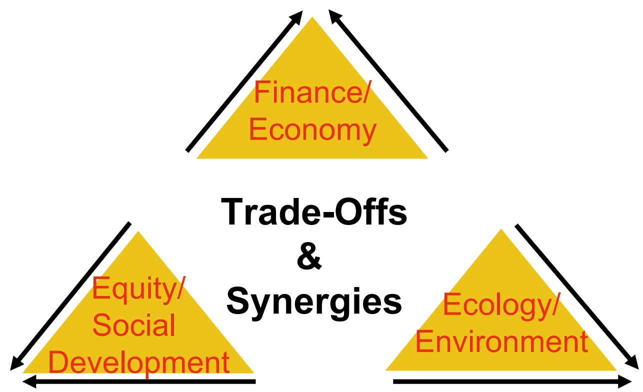
Outline

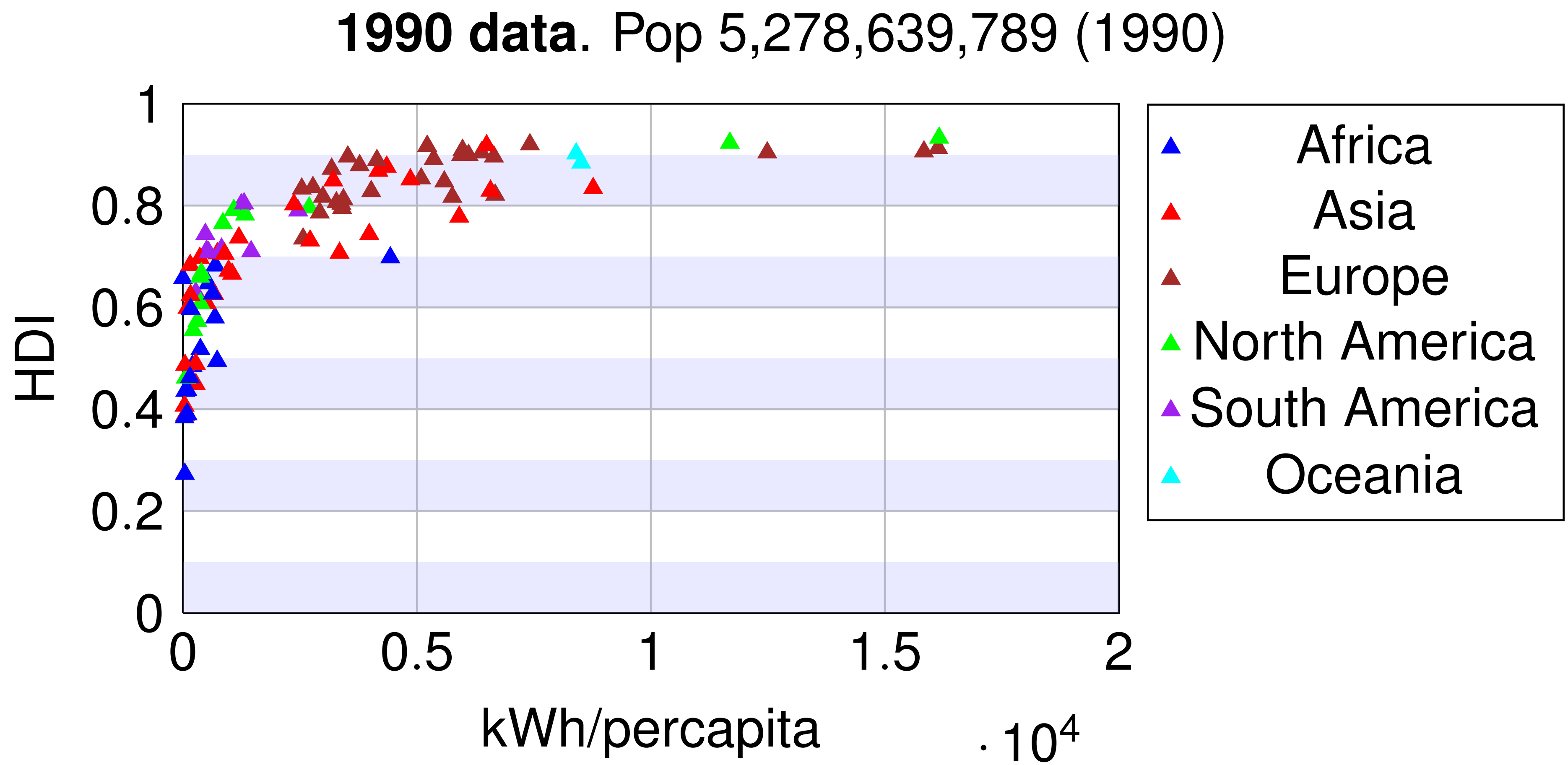
1. Another definition of sustainability - not running out of things. e.g. land
   - Energy footprint
   - Environmental footprint
   - Ecological footprint
   - Carbon footprint
2. Drivers of Change
3. Opportunities and Barriers; timing issues



Derived from the World Bank (1996)

We are not in steady state

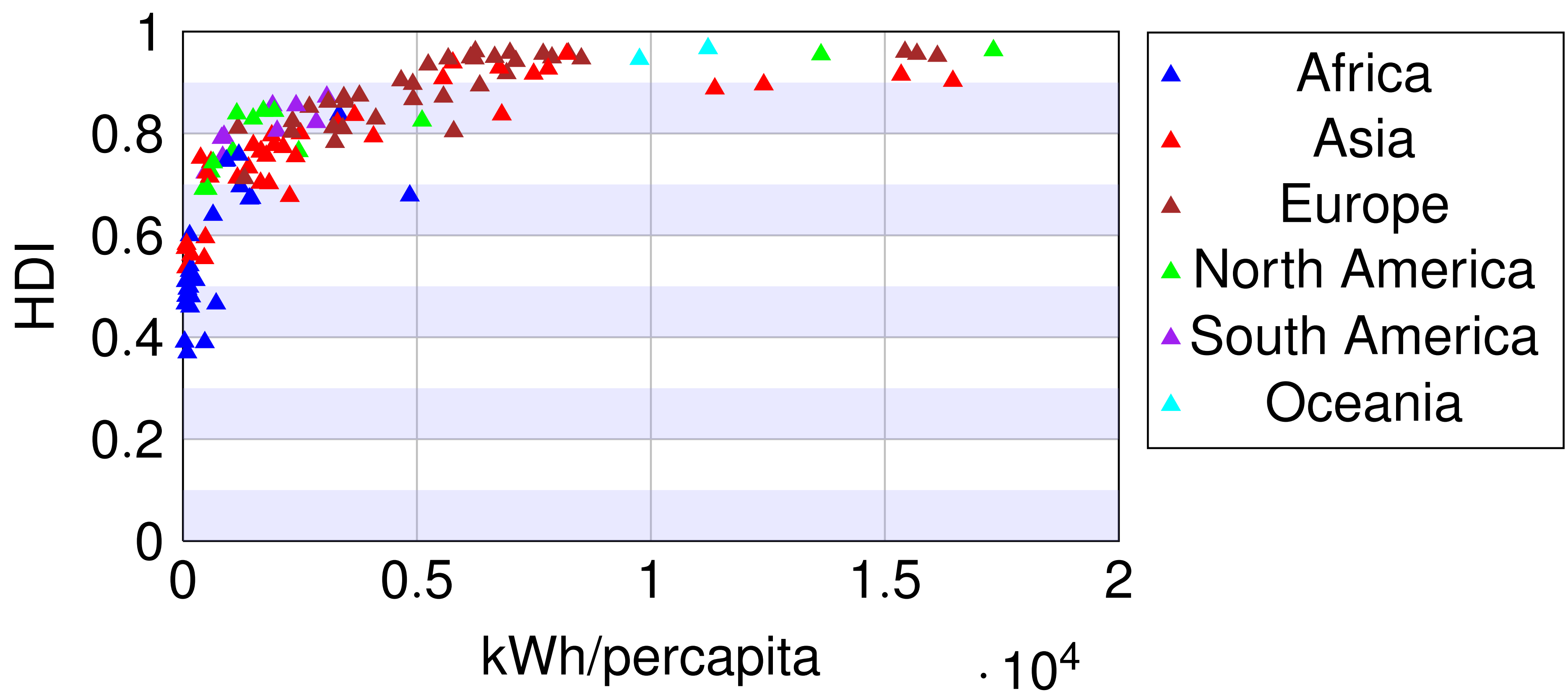
Population and standards of living.



We are not in steady state

Population and standards of living are increasing.

2005 data. Pop 6,486,882,848 (2005)



Along the way, we need to make informed choices.

How do humans impact the environment?

- Need to include direct consumption and also externalities in the supply chain - **life cycle analysis**.
  - Resource depletion (water, energy, food, manufactured materials, fertile land, habitats, etc.)
  - Waste product pollution
  - Interference in environmental balances.
- Need a metric to apply across technologies and consumption. How do I compare an egg to a light bulb?
  - Energy used - convert all energy requirements into a common unit like TOE (tonnes of oil equivalent). Need to convert all usage to primary energy (e.g., including the inefficiency of electricity production from primary energy).
  - CO2 emitted - Here the energy footprint is weighted for the carbon intensity of the primary energy sources. (may not even be zero for nuclear or renewables)
  - Land area used - a computation of land needed to collect water, to grow food, to produce various resources, to convert fossil energy to land to produce equivalent biomass energy, etc. for our individual use.

Carbon emission factors from energy use

The Kaya equation relates CO2 emissions to other quality factors:

CO_2 = Pop $\times$ Standard of living $\times$ Energy Intensity $\times$ Carbon intensity

- Pop represents global population
- Standard of living is in GDP/pop
- Energy intensity is energy used to produce in BTU/GDP
- Carbon intensity is efficiency of fuel and how much CO2 emitted in CO_2/BTU

KAYA DATA

Region	Average Annual Percent Change 1980-1999				
	Population	Standard of Living	Energy Intensity	Carbon Intensity	Carbon Emissions
Africa	2.54%	- 0.58%	0.82%	- 0.01%	2.77%
Australia	1.36%	1.98%	- 0.37%	0.00%	2.98%
Brazil	1.61%	0.76%	1.83%	- 0.80%	3.43%
China	1.37%	8.54%	- 5.22%	- 0.26%	4.00%
East Asia	1.78%	5.00%	0.92%	- 0.70%	7.10%
E. Europe	0.44%	- 1.91%	- 0.14%	- 0.61%	- 2.21%
India	2.04%	3.54%	0.27%	0.03%	5.97%
Japan	0.41%	2.62%	- 0.57%	- 0.96%	1.47%
Middle East	2.98%	0.04%	2.45%	- 1.14%	4.34%
OECD	0.68%	1.73%	- 0.88%	- 0.58%	0.94%
OECD-Eur.	0.53%	1.74%	- 1.00%	- 1.06%	0.18%
United States	0.96%	2.15%	- 1.64%	- 0.21%	1.23%
World	1.60%	1.28%	- 1.12%	- 0.45%	1.30%

WHY DOES ECOLOGICAL FOOTPRINT MATTER

Footprints are about measuring how much of a finite resource you are using.

- Carrying capacity of earth?
- Sustainable economies, societal institutions, and the environment
    - Ecological footprints for modest European lifestyle are 2.6 hectares or about 6.5 acres per person
        - US average = 24 acres per person (8.8 hectares)
        - UK average = 5.3 hectares per person (13.3 acres)
    - Above modest European lifestyle applied to China suggests it could support a sustainable population of 333 million! [Optimum Population Trust, UK, 1993]
    - Area of US is similar to China - so US can support its population - at European lifestyle levels! - but we are ~3$\times$ that level.

Discussion

- How much does our location globally have to do with our footprint?
- Solutions? Equity?
- Consequences?

ENERGY FOOTPRINT

- Land used to generate energy
- Land needed to absorb CO_2 emissions from energy generation
- Energy used in an activity or production of an item

SOLAR, HOW DO WE GET FROM 1300 W/M^2 TO 4?

- Solar insolation is 1300 W/m^2 at the top of the atmosphere. => 1GW plant needs 877 m $\times$ 877 m
- Clear air attenuates to 1000 W/m^2 => 1000 m squared
- Only half the Earth is illuminated 500 W/m^2 => 1400 m squared
- The sun rises and sets $\langle \sin\theta \rangle = \frac{1}{2}$ 250 W/m^2=> 2000 m sq
- Cloud cover can cost 25%-50% , but we'll be generous and assume we use deserts.
- Efficiency of solar cells. Take 20%. 50 W/m^2=> 4472 m squared
- Packing efficiency. Solar plants typically only cover 25% with cells or mirrors. e.g. Solarpark Lieberose has 50 ha of cell area on 163 ha of land used by the plant (300 ha overall leased). 25 W/m^2=> 9000 m squared

Ecological footprint

- See http://www.earthday.net/footprint
- What is your footprint?
- My own footprint is not great:
  - Food 3.0 acres
  - Mobility 7.0 acres
  - Shelter 3.2 acres
  - Goods 3.0 acres
  - Services 8.7 acres
  - Total 24.9 acres (about US average)
- Worldwide there are 4.5 biologically productive acres per person. Is there enough to go around?

Should I fly, take the train, or drive to Princeton?

They all take 6 hours. They all cost the same $ (at least for one person). It's 600 miles round trip.

Flying

- A full Boeing 747-400 with 240 000 liters of fuel and 416 passengers can travel 8 800 miles (14 200 km)
- Jet fuel has 10 kWh/liter of heat energy.
- $\frac{2 \times 240000\text{liter}}{416\text{passengers}} \times 10\text{kWh/liter} \simeq 12000\text{kWh per passenger}$
- Pro rate this for my trip: $\times 300/8800 \simeq 400kWh$

Should I fly, take the train, or drive to Princeton?

They all take 6 hours. They all cost the same $ (at least for one person). It's 600 miles round trip.
The train

- A regional train uses 5-15 kWh per 100 seat-mi
- Take the middle range and assume the train is full
- 6×10 kWh per 100 seat-mi $= 600$ kWh

Should I fly, take the train, or drive to Princeton?

They all take 6 hours. They all cost the same $ (at least for one person). It's 600 miles round trip.

Driving

- A single passenger in a non-hybrid getting 30 mi/gallon.
- Gasoline has about 44 kWh per gallon.
- $\frac{600\text{mi}}{30\text{mi per gallon}} \times 44\text{kWh/gallon} \simeq 880\text{kWh}$

Discussion

- It is said the Gobi desert could supply the world's power if covered in photovoltaic cells. Is this true? The Gobi desert is approximately 1 280 000 square kilometers. What about snow? Practical issues?
- How much can we reasonably reduce our footprints?
- When you are a working professional, do you hope to have a larger footprint? Do you care?
- What other choices did I have for short trips? What other considerations?

Drivers of Change - for discussion

- Technological innovation
  - Will it enable painless transition to sustainable lifestyles. eg Firelight -> Lightbulb -> CFL -> LED
  - What are you willing to give up? Does life style = quality of life?
- Substitution of alternatives
  - Zipcar, hybrids, public transport
  - Desktop(300W) -> laptop(60W) -> Smartphone (5W)
- Policy and regulatory requirements. Is regulation the way to go? What about personal freedoms? Will the market decide/respond? Recycling, incandescent bulbs (2012 efficiency standards 14->45 lumens/W)
  Related closely to adoption and development of technologies. Refrigerators as a historical example resisted by industry.
- Changes in people's preferences. Social pressure. What have you observed compared to say 20 yrs ago? greening of industries? Why?

Opportunities and Barriers; timing

- Technologies
  - Market barriers - costs. Maybe subsidies are required? eg solar and wind.
  - Inertia - infrastructure investment payout, consumer preferences
- Policy - Stimulus fund, cash-for-clunkers, grid and other infrastructure upgrades. Creating jobs, but opportunity to adopt new more efficient infrastructure.

Some resources

- Sustainable Energy; Tester et al.
- Sustainable Energy, Without the hot air; MacKay at http://www.withouthotair.com/
- Earthday footprint analysis at http://www.earthday.net/footprint
- Carbonfund Carbon footprint calculator at http://www.carbonfund.org/site/pages/calculator/

22.081J / 2.650J / 10.291J / 1.818J / 2.65J / 10.391J / 11.371J / 22.811J / ESD.166J
Introduction to Sustainable Energy
Fall 2010