Chapter 1. An Introduction to Sustainability

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1. The IPAT Equation

Use the IPAT equation to estimate the percentage increase in the amount of energy that would be required, worldwide, in 2050, relative to 2006. To estimate the increase in population and affluence (the P and A in the IPAT equation), assume that population grows 1% per year and that global economic activity per person grows 2% per year. Assume that the energy consumption per dollar of GDP (the T in the IPAT equation) remains at 2006 levels. How much does this estimate change if population growth is 2% and economic growth is 4%?

<u>Solution:</u>

$I_{2006} = P_{2006}\ A_{2006}\ T_{2006}$

At 1% population growth per year and 2% per capita economic growth for 44 years:

$I_{2006}/I_{2006} = (P_{2006}/P_{2006})\ (A_{2006}/A_{2006})\ (T_{2006}/T_{2006}) = (1.01)^{44}(1.02)^{44}(1) = 3.7$

At 2% population growth per year and 4% per capita economic growth for 44 years:

$I_{2006}/I_{2006} = (P_{2006}/P_{2006})\ (A_{2006}/A_{2006})\ (T_{2006}/T_{2006}) = (1.02)^{44}(1.04)^{44}(1) = 13.4$

2. Affluence and energy use

Estimate the amount of energy that will be used annually, worldwide, if over the next 50 years world population grows to 10 billion and energy use per capita increases to the current per capita consumption rate in the US. What percentage increase does this represent over current global energy use?

<u>Solution:</u>

10 billion people * 330 million BTU/person/yr (from Example Problem 1.3-1) = 3300 Quadrillion BTU

This is roughly 7 times the current world energy consumption of 450-500 Quads

3. Energy efficiency in automobiles

Assume that the conversion of energy into mechanical work (at the wheel) in an internal combustion engine is 20%. Calculate gallons of gasoline required to deliver 30 horsepower at the wheel, for one hour.

<u>Solution:</u>

1 HP = 746 Watts
1 HP for 1 hour is 0.746 kWh
0.746 kWh * 3412 BTU/kWh = 2545 BTU
2545 BTU * 1 gal gasoline/124000 BTU * 1/0.2 = 0.1 gal

4. Water use by automobiles
Assuming that generating a kilowatt hour of electricity requires an average of 13 gallons of water (Example 1.4-3) and that an average electric vehicle requires 0.3 kWh/mi traveled (Kintner-Meyer, et. al., 2007), calculate the water use per mile traveled for an electric vehicle. If gasoline production requires approximately 10 gallons of water per gallon produced and an average gasoline powered vehicle has a fuel efficiency of 25 miles per gallon, calculate the water use per mile traveled of a gasoline powered vehicle.

Solution:
Water use per mile (electric vehicle) = 0.3 kWhr/mi * 13 gal/kWh = 4 gal/mi
Water use per mile (gas vehicle) = 10 gal water/gal gasoline * 1 gal gasoline/25 mi = 0.4 gal/mi

5. Energy efficiency in lighting
Assume that a 25 watt fluorescent bulb provides the same illumination as a 100 watt incandescent bulb. Calculate the mass of coal that would be required, over the 8000 hour life of the fluorescent bulb, to generate the additional electricity required for an incandescent bulb. Assume transmission losses of 10%, and 40% efficiency of electricity generation, and 10,000 BTU/lb for the heat of combustion of coal.

Solution:
The additional electricity required by the incandescent bulb is 75 watts over 8000 hours or 600 kWh. At 3412 BTU per kWh this is $2.05 * 10^6$ BTU. To generate this much electricity we need:

BTU primary fuel = $2.05 * 10^6$ BTU/((1-.1)(.4)) = $5.7 * 10^6$ BTU

$5.7 * 10^6$ BTU/(10,000 BTU/lb coal) = 570 lb coal

6. Energy Savings Potential of Compact Fluorescent versus Incandescent Light Bulbs
Compact fluorescent light bulbs provide similar lighting characteristics as incandescent bulbs, yet use just ¼ of the energy as incandescent bulbs. Estimate the energy savings potential on a national scale of replacing all incandescent bulbs in home (residential) lighting applications with compact fluorescent bulbs. In 2008, total U.S. energy consumption was 99.3 quadrillion (10^{15}) BTUs (quad) and electricity in all applications consumed 40.1 quads of **primary** energy. Assume that residential lighting is 3% of all electricity consumption in the U.S. and that all energy consumption for residential lighting is due to incandescent bulb use. How large (%) is the energy savings compared to annual U.S. energy consumption (2008 reference year)? Is this savings significant?

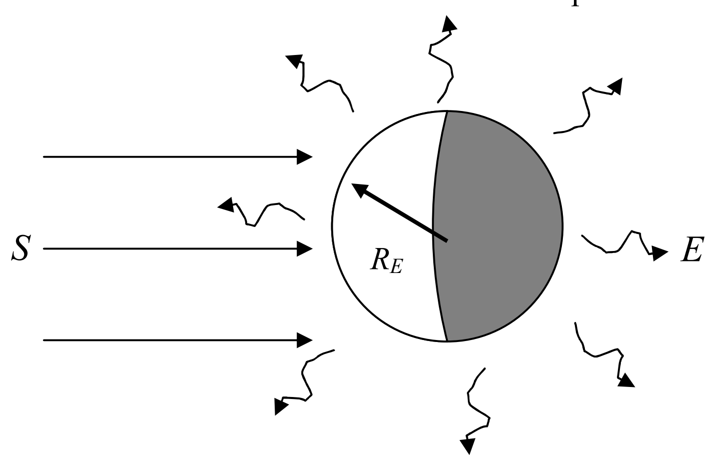
Solution:
Assuming incandescent bulb provide current residential lighting,
Current Primary Energy for Residential Lighting = (.03)(40.1 quads) = 1.2 quads

If fluorescent bulbs provided this residential lighting, primary energy consumed would be (1.2 quads)(¼) = 0.3 quads

Savings of primary energy is 1.2 – 0.3 = 0.9 quads, or 0.9/99.3 = 0.0091 (0.91%)

Is this savings significant? Yes, with a single change about 1% of energy can be saved. If several other energy saving steps could be found and implemented (insulation in residential homes, efficient lighting in commercial buildings, higher mileage vehicles, etc.), much larger savings could be found. The acceptability of any changes would have to be judged from a consumer standpoint based on economic factors and ease of adoption.

7. Global Energy Balance: No Atmosphere (adapted from Wallace and Hobbs, 1977)
The figure below is a schematic diagram of the earth in radiative equilibrium with its surroundings assuming no atmosphere. Radiative equilibrium requires that the rate of radiant (solar) energy absorbed by the surface must equal the rate of radiant energy emitted (infrared). Let S be the incident solar irradiance (1,360 Watts/meter^2), E the infrared planetary irradiance (Watts/meter^2), R_E the radius of the earth (meters), and A the planetary albedo (0.3). The albedo is the fraction of total incident solar radiation reflected back into space without being absorbed.



a) Write the steady-state energy balance equation assuming radiative equilibrium as stated above. Solve for the infrared irradiance, E, and show that it's value is 238 W/m^2.

Solution:
Energy Balance:

"Rate of Solar Energy Absorbed" = "Rate of Infrared Energy Emitted"

$$(1-A)\, S\, \pi\, R_E^2 = E\, 4\, \pi\, R_E^2$$

$$E = \frac{(1-A)S}{4} = \frac{(1-.3)(1{,}360\,\text{Watts}/m^2)}{4} = 238\ \text{Watts}/m^2$$

b) Solve for the global average surface temperature (K) assuming that the surface emits infrared radiation as a black body. In this case, the Stefan-Boltzman Law for a blackbody is $E = \sigma T^4$, σ is the Stefan-Boltzman Constant (5.67x10^{-8} Watts/(m^2•˚K^4)), and T is absolute temperature (˚K).