Solutions to exercises

Chapter 1 Introduction

Short answers:

1.1 Open-ended discussion question; see below.

1.2 Open-ended discussion question; see below.

1.3 HDI = 0.736; not in line with other countries

1.4 **(a)** see figure, **(b)** discussion question, **(c)** $R^2 = 0.457$, **(d)** $R^2 = 0.0241$, **(e)** and **(f)** discussion questions

1.5 33.9, 29.5, 18.9, 23.0 EJ

1.6 98.6, 22.5, 38.8, 13.6 quads

1.7 Rank order: India, China, United States, Japan

1.8 140.4, 248, 22.3, 30.8, 81.9 mtoe

1.9 See explanation below.

Detailed answers:

1.1. Use the Internet or other resources to chart the development of an energy technology, from its earliest beginnings to the present day. Did the roots of this technology first emerge prior to the start of the industrial revolution? If so, how? If not, when did the technology first emerge? In what ways did the industrial revolution accelerate the growth of the technology? More recently, what has been the impact of the information age (e.g., computers, software, electronically controlled operation, the Internet, etc.) on the technology?

- *Answer:* A variety of answers are possible. For example, for wind energy, the roots of the technology predate the industrial revolution, dating back to the middle ages in Europe and earlier to use of wind for grinding grain in China and the Middle East. The industrial revolution made possible metallurgical techniques, which in turn enabled the precision fabrication of turbine blades, electrical components, etc., used in wind electric conversion devices. Since the 1970s, information technology has been used computationally to improve the shape of the turbine blades or operationally to integrate electricity from the turbine into the grid.
- Alternatively, for solar energy: solar energy predates the industrial revolution, in that the use of passive solar design to heat buildings or keep them cool goes back to the Ancient Greeks, the Chinese, and the Native Americans of the southwest. Also, solar drying of clothes and food has been practiced since antiquity. The industrial revolution accelerated the growth of solar energy by making possible metallurgical techniques, which in turn enabled the precision fabrication of experimental solar-powered, steam-driven devices starting in the late 1800s. They also made possible home-sized solar water heating systems for domestic

hot water. Since the 1970s, information technology has been used computationally to control the manufacture of solar panels, or to operate tracking systems that optimize the position of solar panels relative to the sun.

1.2. *Note to instructors: it may be preferable to provide the students with the raw data for the three countries used in this exercise, if you wish to save them time on the data gathering and focus on the calculations and analysis.*

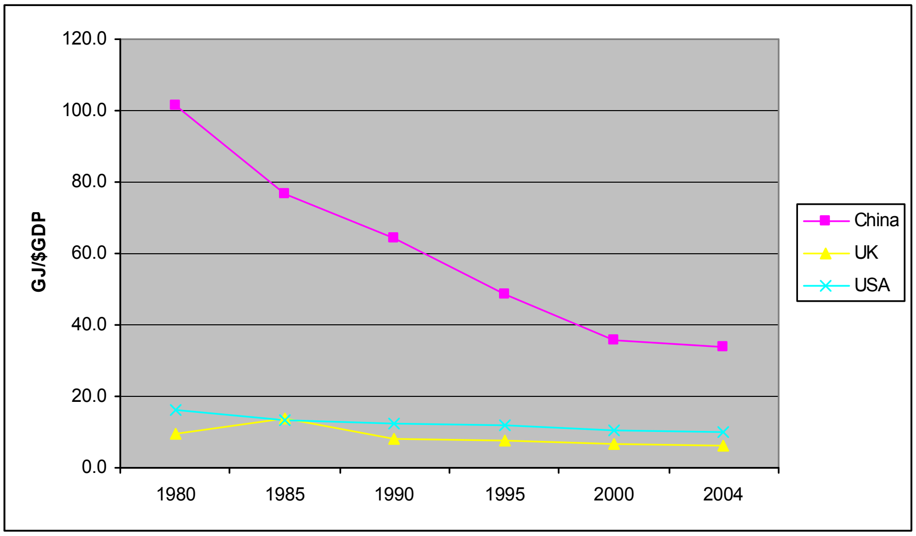
Solution: From studying the accompanying graphs, it is clear that the trend in the United Kingdom more closely resembles that of the United States than that of China.

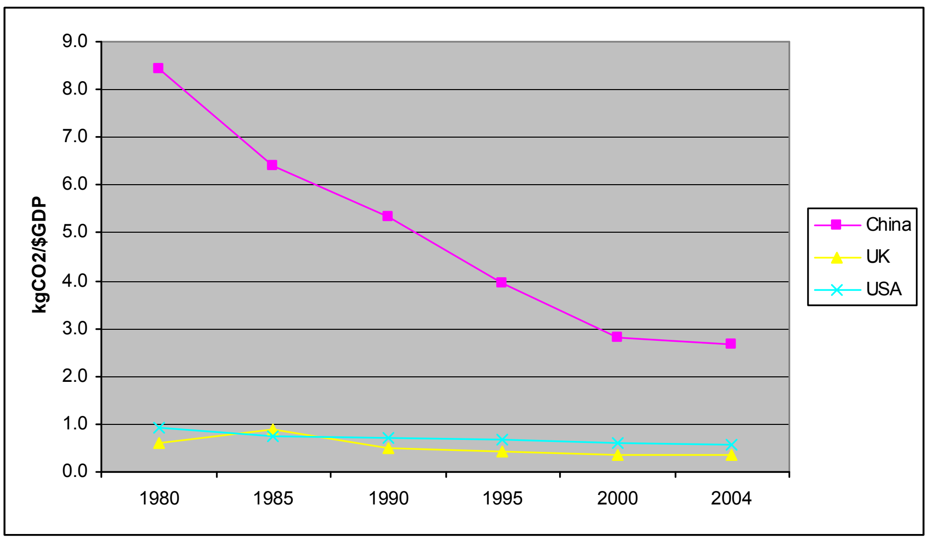
On the GDP side, both the United States and the United Kingdom have gradually been decreasing energy and CO_2 emissions per unit of GDP produced, although the United Kingdom is somewhat more efficient than the United States in producing a unit of GDP. This is different from China, which saw dramatic reductions in energy and CO_2 emissions per unit of GDP between 1980 and 2000, although these are perhaps slowing after 2000.

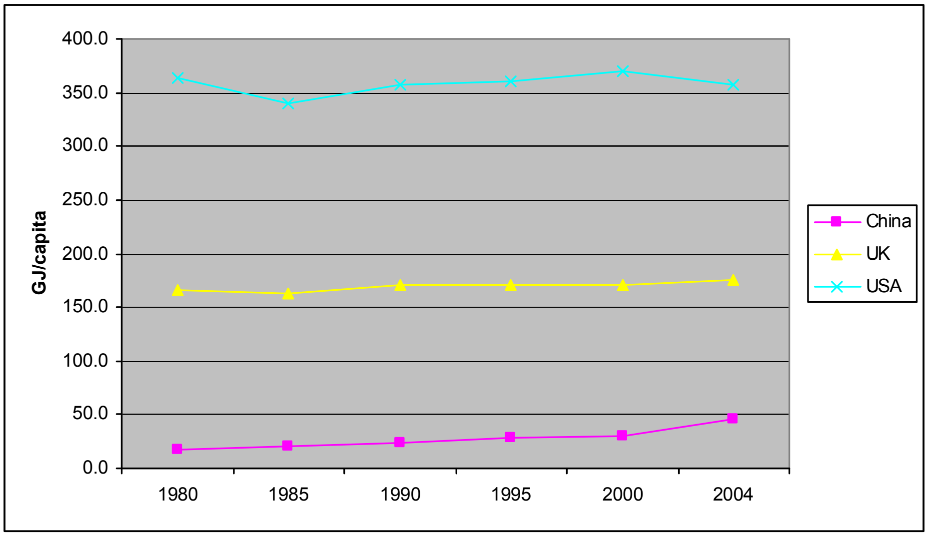
On the population side, energy consumption per capita is slightly up for the United Kingdom and the United States and CO_2 emissions per capita are slightly down for the period in question. This suggests that both countries are reducing the amount of CO_2 per unit of energy consumed. China is much lower in per capita measures than the other two countries, but is seeing an upturn in both since 2000, so that it appears that in the most recent years, China is moving in a different direction than the other two countries. Since 1995 or so, China is growing a much larger middle class, so it is not surprising that energy and CO_2 might turn upward in this way.

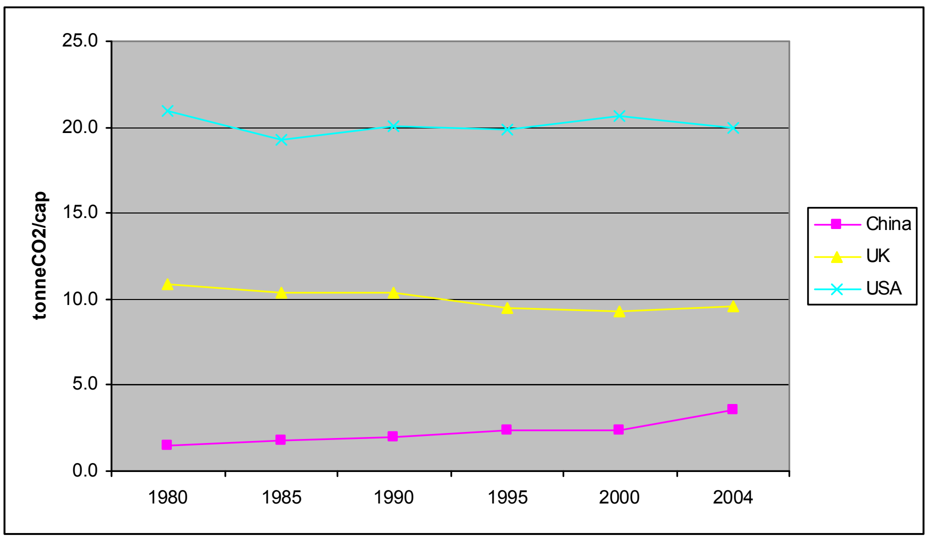
In general, the shape of the figures varies little whether one compares the three countries in terms of per unit of energy or per unit of CO_2 emitted. The most profound change has been the reduction in energy and CO_2 per unit of economic activity in China. Compared to this trend, all other measures have not changed as much.

Figures to accompany Problem 1.2:


120.0
100.0
80.0
60.0
40.0
20.0
0.0
GJ/$GDP
1980
1985
1990
1995
2000
2004
China
UK
USA


9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
kgCO2/$GDP
1980
1985
1990
1995
2000
2004
China
UK
USA





1.3. The country of Fictionland has 31 million populations and consumes on average 12.09 exajoule (EJ), or 11.46 quads, of energy per year. The life expectancy of Fictionland is 63 years, and the GDP per capita, on a PPP basis, is $13,800. The adult literacy rate is 75%. The eligible and actual student enrollments for primary, secondary, and college/university levels of education are given in the table below:

	Eligible	**Enrolled**
Primary	2,500,000	2,375,000
Secondary	2,100,000	1,953,000

University	1,470,000	558,600

Questions:

a. Calculate the HDI for Fictionland.

b. How does Fictionland's HDI to energy intensity ratio compare to that of the countries in the scatter charts in the chapter? Is it above, below, or on a par with these other countries?

Solution: Part (a): Calculate components of HDI as follows:

Life expectancy:

$$\frac{(63-25)}{(85-25)} = 0.633$$

CGER calculation:

Primary: 2.375M / 2.5M = 0.95

Secondary: 1.953M / 2.1M = 0.93

University: 558.6K / 1.47M = 0.38

CGER: (0.95 + 0.93 + 0.38) / 3 = 0.751

Educational index:

$$\frac{2(0.75)}{3} + \frac{1(0.753)}{3} = 0.751$$

GDP calculation:

$$GDPFactor = \frac{Log_{10}(13800) - Log_{10}(100)}{Log_{10}(40000) - Log_{10}(100)} = 0.822$$

The HDI is then the average of the three factors, or 0.736.

Part (b): Fictionland lies below the curve for the other countries.

1.4. Regression analysis of population, economic, and environmental data for countries of the world. For this exercise, download from the Internet or other data source values for the population, GDP in either unadjusted or PPP form, energy consumption, and land surface area of as many countries as you can find. (Note to instructors: a possible data set is available in the spreadsheet workbook that accompanies this instructor's manual suite.) Then answer the following questions:

a. From the raw data you have gathered, create a table of the countries along with their GDP per capita, energy use per capita, and population density in persons per square kilometer or square mile.
b. In part (a), did your data source allow you to include figures for all three measures for all the major countries of all the continents of the world? If not, what

types of countries was it not possible to include, and why do you suppose this might be the case?
c. Using a spreadsheet or some other appropriate software, carry out a linear regression analysis of energy consumption per capita as a function of GDP per capita. Produce a scatter chart of the values and report the R^2 value for the analysis.
d. One could also speculate that population density will influence energy consumption, since a densely populated country will require less energy to move people and goods to where they are needed. Carry out a second regression analysis of energy consumption per capita as a function of population density. Produce a scatter chart of the values and report the R^2 value for the analysis.
e. Discussion: Based on the R^2 value from parts (c) and (d), how well do GDPpc and population density predict energy consumption? What other independent variables might improve the model? Briefly explain.
f. Given the global nature of the world economy, what are some possible flaws in using energy consumption figures broken down by country to make statements about the relative energy consumption per capita of different countries?

Solution:

a. *Preprocess: from the raw data given, create a table of the countries to be included in the model and the dependent and independent variable values for each countries. Note: for simplicity and ease of grading, please do not augment the data set with figures that you find in other sources.*

ANSWER: Align the data so there is corresponding energy/cap, GDP/cap, and population/area data for each country. Calculate these variables by dividing the total energy consumption by the country population, total GDP by population, etc. Table not shown for brevity.

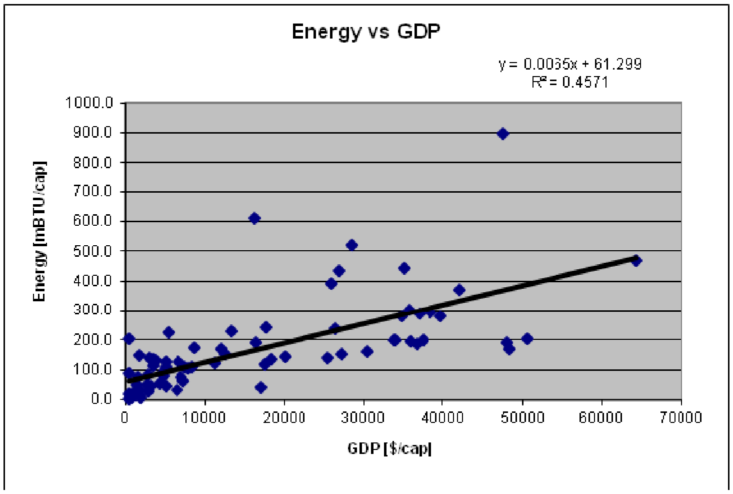
b. *Note that in part (a) not all countries are included. What can you say about the countries which are typically left out of this list? A one- to two-sentence answer is fine.*

ANSWER: The data contain an estimated 96.6% of the total world energy consumption, and 85.8% of the total world population. Thus, the countries left out have lower energy consumption/capita than the countries evaluated. We also may infer that these are third-world countries where energy consumption, GDP, and population estimates may not be as readily available. Other answers also accepted.

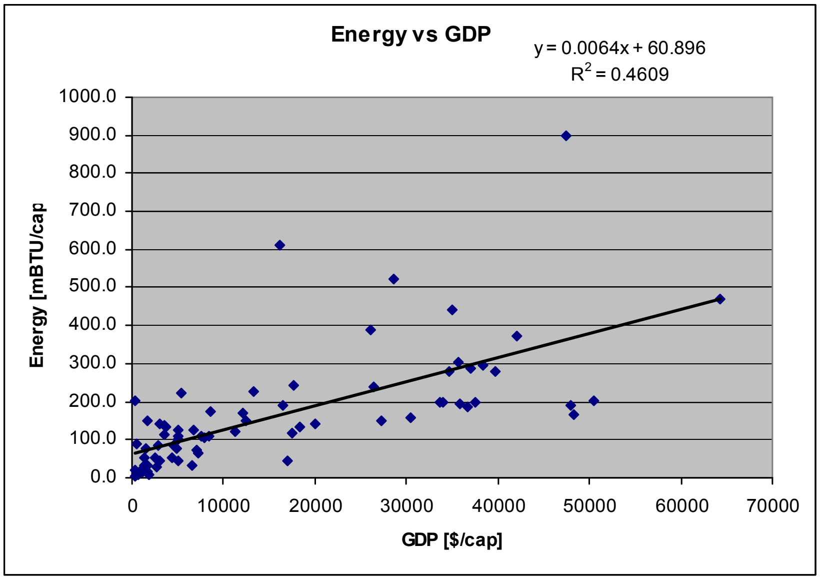
c. *Solve for the parameters a and b for the correlation between energy/capita and GDP/capita using Excel or some other package. Also, give the R^2 value and plot a scatter chart with curve fit.*

ANSWER: a = 61.3 (million Btu/capita), b = 0.0065 (million Btu/GDP)

Note: Answers may vary slightly due to students not including one of the countries in the analysis, if the country is an "outlier" (e.g., Hong Kong, Singapore).

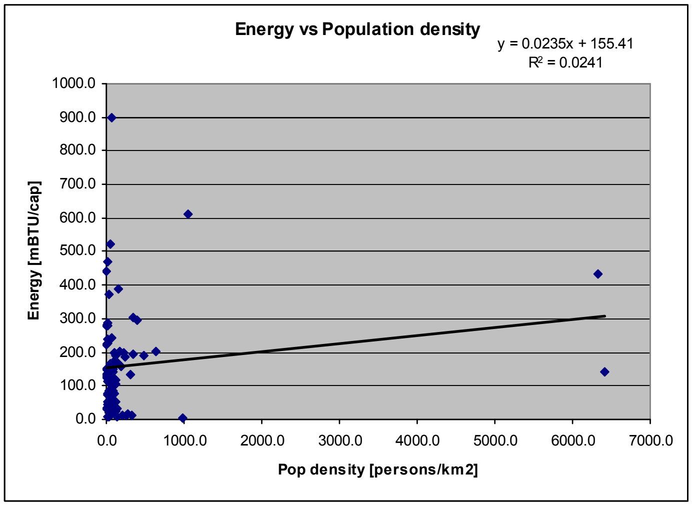


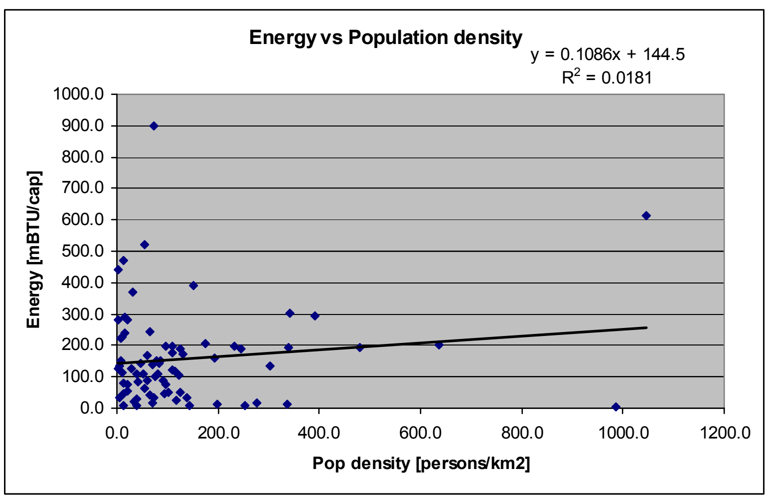
(Removed outliers: Hong Kong, Singapore)



d. *Now solve for the parameters a and b for the correlation between energy/capita and population density, and also solve for the R^2 value for the model and plot a scatter chart with curve fit.*

ANSWER: a = 155.41 (million Btu/capita), b = 0.00235 (million Btu/pop. density)





e. *Discussion: Based on the R^2 value from part (d), how well do GDP and population density predict energy consumption? What other independent variables might improve the model? You can describe these variables and explain in words how they might help, but you do not need to carry out any calculations (1 page maximum).*

ANSWER: GDP is shown to be a rather effective predictor of energy consumption, with a visually linear positive trend and an R^2 of 0.46.

Population density is not an effective predictor with a very low R^2 (0.02), with the slope largely influenced by countries with large population densities (Hong Kong and Singapore). There are potentially many variables that could improve the fit of the model; a few examples could be:

- Climate
- Policy metrics (e.g., Kyoto protocol membership, democratic government)
- Metrics of transportation network (e.g., miles of paved road, miles of railroad, etc.)
- Metrics of energy resources (e.g., oil production from country, nuclear technology)

f. *Discussion: Given the global nature of the world economy, what is a possible flaw in using energy consumption broken down by country to make statements about energy consumption per capita? One paragraph maximum.*

ANSWER: Energy consumption of a country does not necessarily mean that all the energy was used to make goods or provide services by the people of that country. For example, China produces many manufactured goods that are subsequently consumed by citizens in the United States. So, this may make Chinese citizens appear to be consuming more energy, when it should in reality be attributed to American citizens. Similar arguments could be made for other products, including oil, which can require an energy intensive process to extract and refine before exporting to other countries.

1.5 According to the U.S. Department of Energy, in 2005 the United States' industrial, transportation, commercial, and residential sectors consumed 32.1, 28.0, 17.9, and 21.8 quads of energy, respectively. What are the equivalent amounts in EJ?

Solution: Multiply each value by 1.055 EJ/quad. Thus, the values are for the four sectors, respectively: 33.9, 29.5, 18.9, and 23.0 EJ.

1.6 From Fig. 1-8, the energy consumption values in 2000 for the United States, Japan, China, and India are 104, 23.7, 40.9, and 14.3 EJ, respectively. What are these same values converted to quads?

Solution: Multiply each value by 0.948 quad/EJ. Thus, the values are for the four countries, respectively: 98.6, 22.5, 38.8, and 13.6 quads.

1.7 Also for 2000, the estimated total CO_2 emissions for the four countries given in Problem 1.6 were 5970 MMT, 1190 MMT, 2986 MMT, and 1048 MMT, respectively. Create a list of the four countries, ranked in order of decreasing carbon intensity per unit of energy consumed. Give the units in either tonnes CO_2 per terajoule (TJ) or tons per billion Btu consumed.

Solution: The rank order is India, China, United States, and Japan. Solved here in are metric units. For each country, divide total carbon by total energy. In rank order: 1048 MMT/14.3 EJ = 73.3 tonnes/TJ; 2986 MMT/40.9 EJ = 73.0 tonnes/TJ; 5970 MMT/2014 EJ = 57.4 tonnes/TJ; 1190 MMT/23.7 EJ = 50.2 tonnes/TJ. In standard units, the values are 85.0 tons/bil.Btu, 84.7 tons/bil.Btu, 66.6 tons/bil.Btu, 58.3 tons/bil.Btu.

1.8 Convert the energy consumption values for the countries of Australia, Brazil, Israel, Portugal, and Thailand from Table 1-1 into units of million toe.

Solution: From the table, the starting values are 5.98, 10.56, 0.95, 1.31, and 3.49 EJ, respectively. Multiplying by 23.47 mtoe per EJ gives, respectively: 140.4, 248.0, 22.3, 30.8, and 81.9 mtoe.

1.9 Use the description of the derivation of the horsepower unit by James Watt and others to show that 1 hp = 746 W, approximately.

Solution: Based on the paper: Smith, H. (1936). "The Origin of the Horsepower Unit." *American Journal of Physics*, Vol. 4, No. 3, pp. 120–122. According to Watt's text, the horsepower is based on a horse moving 2.5 mph and drawing 150 lb of weight up a shaft (i.e., over a pulley, and ignoring frictional losses in the pulley). This is equivalent to 13,200 ft/h, or, taking into account the weight being lifted, 1.98 million ft-lb/h, or 33,000 ft-lb/min. From www.onlineconversions.com, 1 ft-lb/min is equal to 22.6 milliwatts. Multiplying out gives 33,000 × 0.0226 = 746 watts.