MONT 104N – Modeling the Environment
Chapter 3 Project
September 28 and October 1, 2018

Introduction

To solidify your confidence in dealing with quantitative information, this project summarizes ideas developed in the previous two chapters, as well as a few data visualization topics that we have not mentioned before. The subject will be the whole United States energy economy in recent years.

Background

This project is inspired by a similar project developed for the book *Quantitative Reasoning and the Environment* by Greg Langkamp and Joseph Hull (Prentice Hall, 2007), but uses different and more recent data.

Figure 1 shows estimated energy production and end-use consumption data for all major sectors in the United States energy economy for the year 2017. Figure 2, given later, shows the analogous data for the year 2010. Similar diagrams have been produced each year by the Lawrence Livermore National Laboratory, using data provided by the Energy Information Administration, a division of the U.S. Department of Energy.

Reading the Charts

To read these diagrams, you will want to rotate the page or the screen by 90° clockwise, then follow the flow of energy by reading from left to right. On the far left are boxes representing the major energy sources labeled Solar, Nuclear, Hydro, Wind, etc. The 4 boxes towards the right (Residential, Commercial, Industrial, Transportation) are the four largest end-use sectors of energy consumption. Some of the basic source energy is first converted to electricity before it is transmitted to the four end-use sectors, as shown by the box labeled "Electricity Generation."[1] On the far right, two boxes in the diagram indicate the total amount of energy that is lost or wasted ("Rejected Energy") and the amount that is used for its intended purpose ("Energy Services"). The "pipelines" joining the boxes represent how much energy originating in the box to the left was delivered to the box on the right. The numerical amounts are given as the numbers printed next to the pipelines in units to be discussed below.[2] The width of each energy flow (pipeline) is also in direct proportion to the amount of energy in that flow so you can judge the importance visually.

Units

The header on the top of the chart states that the estimated total energy consumption in 2017 was 97.7 Quads. This means 97.7 quadrillion BTUs. One quadrillion is 1×10^{15}. All energy

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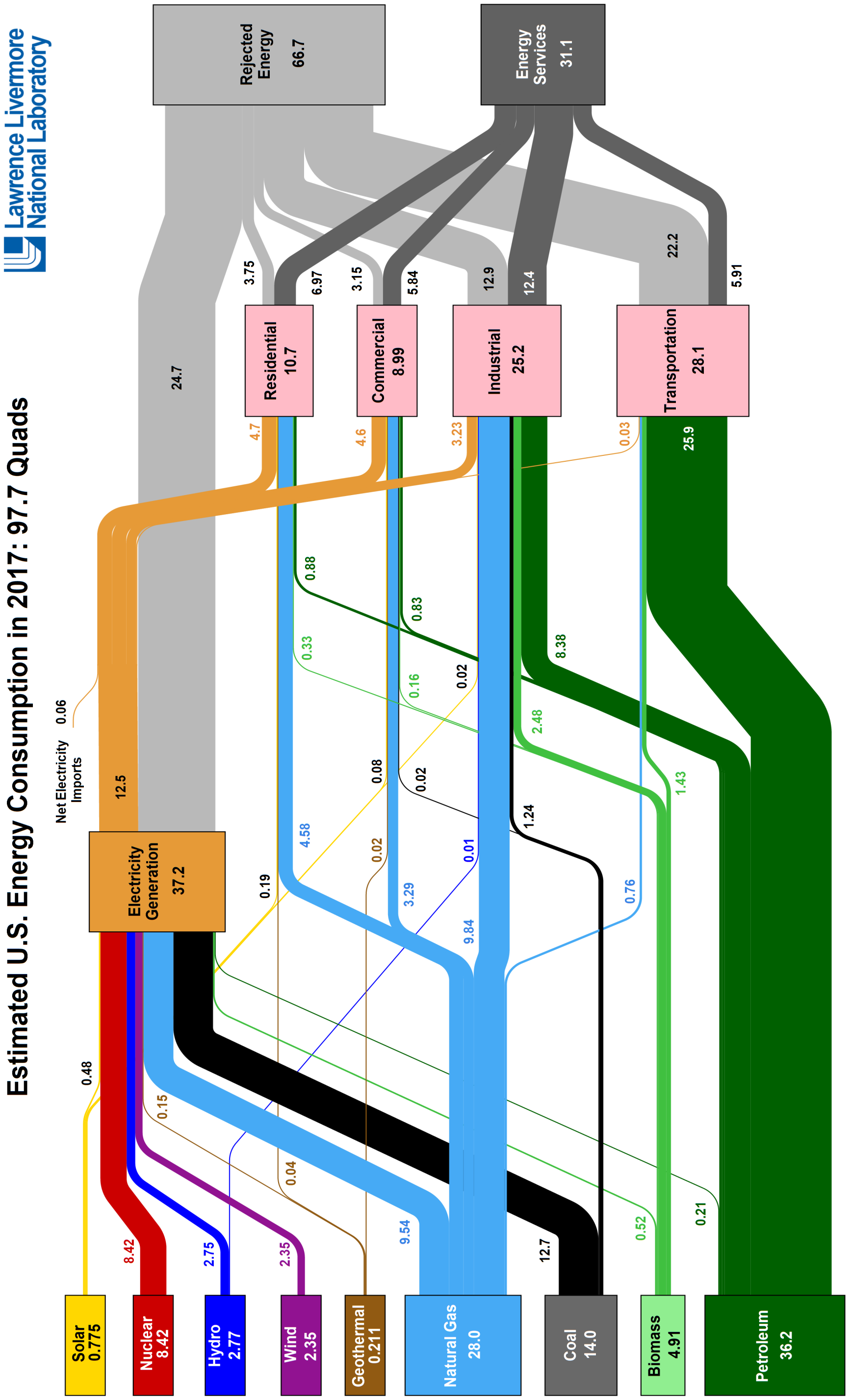
[1] At the top of the diagram, you can also see that there is a very small amount of electric energy that was imported (mostly from hydroelectric plants in Canada). This is so small that it is essentially negligible in the big picture.

[2] The numbers aren't always near the source, so you may need to hunt for them!


Estimated U.S. Energy Consumption in 2017: 97.7 Quads

Source: LLNL April, 2018. Data is based on DOE/EIA MER (2017). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. This chart was revised in 2017 to reflect changes made in mid-2016 to the Energy Information Administration's analysis methodology and reporting. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 21% for the transportation sector, and 49% for the industrial sector which was updated in 2017 to reflect DOE's analysis of manufacturing. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Figure 1: The U.S. energy sector in 2017.

measurements on the diagram have units of quadrillion British thermal units (BTU's), or "Quads" for short. The BTU is an English system unit of energy; we use it rather than a corresponding metric unit because that is the way these charts from the Lawrence Livermore National Laboratories are reported to interested parties in the United States. One BTU is the quantity of heat needed to raise the temperature of 1 pound of water by 1° F at or near 39.2° F. Some approximate conversion factors for the energy content of common energy sources are given below, in units typically used to measure those forms of energy by consumers. In most cases, the numbers on the chart have been rounded to 1 or 2 decimal places (tenths or hundredths of a Quad). Because of this rounding, the total Quads listed next to each production sector and end-use sector might not exactly equal the sum of the individual components.

Table 1: Energy content of various energy sources.

Energy source	Equivalent (BTU)
1 ton coal	$21,400,000$
1 barrel (42 gal.) oil	$5,800,000$
1 cubic foot natural gas	1000
1 kilowatt-hour electricity	$3,400$

Questions

(A) Rank the energy sources from highest to lowest in Quads and compute the percentage each accounts for in the total U.S. energy sector. Construct a *pie chart* representing this information. (You can do this in Excel, for instance, or construct the pie chart by hand.)

(B) Using Table 1, determine the answers to the following.

(1) What is the equivalent amount of coal used in 2017 in units of tons?

(2) What is the equivalent amount of natural gas used in 2017 in cubic feet?

(C) Construct a table showing the total natural gas energy used by each of the four end-use sectors. Note that some of the natural gas is used for Electricity Generation, and that electricity is then used in the end-use sectors. In other words, do not miss the portion of the end-use sectors that use natural gas by way of electricity generated by burning gas. (How will you account for the fact that only a part of the Electricity Generation is done by burning natural gas?)

(D) Which of the energy sources are based on *fossil fuels*? Which of the energy sources are *renewable energy* sources? What percentage of the total energy produced is accounted for by renewables?

(E) **Analysis of the Electricity Generation sector.** Many sources of energy flow into the electric power sector, which then distributes electricity to the end-use sectors. Petroleum, coal, natural gas and biomass are burned in conventional power plants to produce heat to boil water. The steam from the boiling water spins turbines which then produce electricity. Nuclear fuels can be used to produce electricity in much the same way: nuclear reactions in power plants make the heat which produces the steam, which spins the turbines, which produce the electricity. Other sorts of energy are also used to generate electricity. Both conventional-electric and nuclear-electric power plants have the property that a large amount of the fuel energy is lost in the process of making electricity and then more is lost during transmission along electrical lines.

  (1) The 2017 diagram indicates that the electric power sector converted various energies to 37.2 Quads of electrical energy. What were the top two sources of energy for the electric power sector?

  (2) How many Quads of electricity were successfully distributed from power plants, and how many Quads were lost at the power plants?

  (3) The *efficiency* of an energy system is defined as the percentage of the total energy used for the intended purpose. Determine the efficiency of the U.S. electric power sector, using your previous answers and *ignoring losses after distribution.*

  (4) Natural gas contributed 9.54 Quads of energy to the electric power sector. How many Quads of that contribution were immediately lost by the electric power sector? Explain any assumptions you are making.

  (5) Give two practical reasons why so little electricity is distributed to the transportation sector.[3]

(F) **The industrial sector.** The Industrial sector includes manufacturing industries, mining, construction, agriculture, fisheries and forestry.

  (1) The industrial sector consumed 25.2 Quads through *six* forms of energy.[4] Draw a bar chart to illustrate the number of Quads used for each of those six form of energy. Label each bar with its energy name and amount.

  (2) Natural gas energy is directly consumed by the Industrial sector through the burning of natural gas. But the Industrial sector also consumes natural gas energy indirectly by using distributed electricity. Compute the total Quads of natural gas energy consumed by the industrial sector. Ignore energy losses.

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[3] There is *some* electric power used for transportation, though. The Amtrak Northeast Corridor passenger rail lines between Boston and Washington, DC use electric power, as do most subway and light rail mass transit systems in cities, for instance.

[4] You will need to look carefully to find them all, but they are there!

(G) **Petroleum and transportation.**

(1) The transportation sector is primarily fed by the energy derived from Petroleum, with small contributions from Biomass, Natural gas, and Electricity. What percent of the total Petroleum energy is consumed by the transportation sector? You can ignore the small amount of oil energy that is first converted to electricity.

(2) What percent of the energy consumed by the transportation sector was wasted in 2017? Consider all forms of energy.

(3) Multiply the percentages found in the last two parts to find the percentage of all Petroleum energy that was wasted by the transportation sector. How many barrels of oil is that? How many gallons?

(H) **Heating homes.** Most homes and apartments today are heated with electricity or natural gas. (The exception to this general rule comes in New England, where many homes are still heated by burning oil.) Electric heaters are 100% efficient because all of the energy that goes into the heaters is turned into heat (the intended purpose). Natural gas furnaces vary considerably in how efficiently they burn gas. The most efficient ones turn about 95% of the gas energy into heat (the intended purpose); the other 5% of the gas energy is wasted through the furnace exhaust. Comparing the numbers (100% versus 95%), one could argue that electric heaters are slightly better than even the most efficient gas furnaces. Explain what is wrong with this argument, using numbers to support your answer.

(I) **Electric power again.**

(1) Some of the electricity generated by the Electricity Generation sector was successfully distributed to users, but much was lost in the system (see question (E)). Some of the electricity that is distributed to the Residential, Commercial, Industrial, and Transportation sectors is further wasted (i.e. lost). Compute the total amount of electricity that is wasted after it is transported to these 3 sectors.

(2) Determine the total amount of electric energy that is distributed and then used, and the total amount that is wasted, for the U.S. electric power system.

(3) In your answer to part (2) you were making a certain proportionality assumption about the end-use sectors. Explain.

(J) Based on the 2017 data, if you were asked to recommend *two aspects* of the U.S. energy economy where changes might increase total efficiency most, what would they be? What sorts of changes would be necessary? Would they be matters of better technology, changes in attitudes of people, etc.?

(K) Now consider the diagram for 2010 in Figure 2.

(1) What major changes do you see between 2010 and 2017? Which forms of energy have increased as a share of the total? Which have decreased? What accounts for those changes? What political and social issues are raised by those changes? (If you need to look up information to answer this, as always, document your sources!)

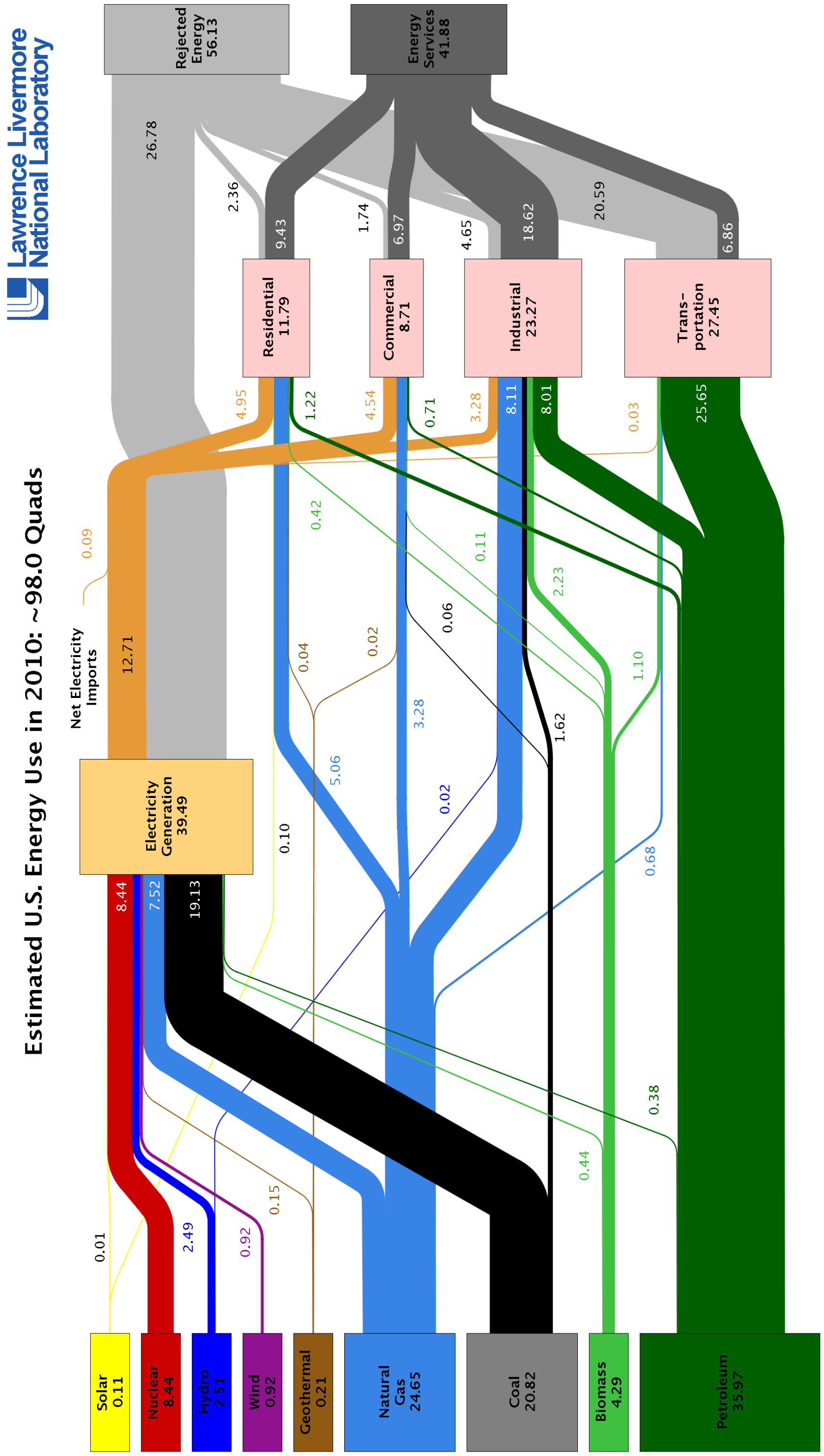
(2) Is the U.S. energy economy more or less efficient in 2017 than it was in 2010? Explain the criteria you are using to derive your answer. Does this surprise you?

Assignment

Write up your computations and answers to the questions above in a technical report.

References for this Project

1 Lawrence Livermore National Laboratory, Energy Flow Charts, downloaded from `https://flowcharts.llnl.gov/commodities/energy`, accessed July 10, 2018.



Source: LLNL 2011. Data is based on DOE/EIA-0384(2010), October 2011. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for hydro, wind, solar and geothermal in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." (see EIA report for explanation of change to geothermal in 2010). The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Figure 2: The U.S. energy sector in 2010.