Power Profiler: Understanding Greenhouse Gas Emissions from Electric Power Generation

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Details ..................................................................................................................................................................... 1
Teaching Notes........................................................................................................................................................ 3
Case Study: Does where I live make a difference in my personal GHG emissions? .............................................. 9
Step-by-Step.......................................................................................................................................................... 10
Tools and Data ............................................................................................................................................................ 12

Details

**Type:** Project module with 3-4 activities to explore electricity generation and use and the resulting greenhouse gas emissions

**Length:** 4 45-minute classes

**Content Area/Course:** Physical science, environmental science, engineering/technology

**Targeted Grade Level:** Adaptable for middle school to undergraduate college students

**Prerequisite Knowledge:** Quantitative ability, some understanding of various resources and processes used to make electricity

**Prerequisite Skills:** Data manipulation and calculation in MS Excel spreadsheet (for college students), basic internet skills

**Technology/web resources:** Internet, MS Excel

**NASA skill development:** Comprehension, synthesis, evaluation

**NASA Resources used:** None

**Description**

Electric power in the United States is primarily generated through the combustion of fossil fuels, with nearly 50% of the total generation attributed to coal combustion. Based on an equivalent amount of electric energy generated, the greenhouse gas (GHG) emissions from coal combustion are nearly twice as much than natural gas, and GHG emissions from nuclear, [2009 U.S. and New York State electric power generation by fuel](http://www.nyserda.org/publications/1995_2009_patterns_trends_rpt.pdf)
hydropower and renewables are negligible. In contrast, New York State uses much less coal for electricity
generation and more hydro and nuclear energy, both of which generate negligible amounts of greenhouse gases.
Thus, how we make electricity, even the choice among which fossil fuel to use, can have a big impact on our
GHG emissions.

This unit explores regional differences in the mix of energy sources used for electricity generation and the
impact of that on regional GHG emissions. Introductory activities help to define efficiency of power plants and
why that is important for understanding lifecycle GHG emissions from electric power production. The unit
culminates in the use of the U.S. EPA Power Profiler tool to explore regional electricity generation mixes and
their associated greenhouse gas emissions.

Although this unit is designed with HS and college level mathematics applications, the general concepts of
efficiency and GHG emissions can be covered in middle school classrooms with less emphasis on the
quantitative aspects.
Teaching Notes

Grade Level
College undergraduates, high school students and middle school students.

Learning Goals
After completing this unit, users will be able to:

- Describe (in general) how electric power is generated
- Identify the major energy resources used in electricity power production and their pros and cons relative to GHG emissions
- Apply emission factors to estimate the total GHG emissions for different energy resources used for electricity
- Relate regional differences in electricity mix to their associated GHG emissions and regional energy resources
- Manipulate data in a spreadsheet to produce graphs
- Analyze pie and bar graphs to interpret differences in electric generation and GHG emissions
- Gain familiarity with the lexicon of electricity generation vocabulary

Rationale
The electric power industry contributed 40% of the total U.S. GHG emissions in 2009. This is attributed to the large quantities of fossil fuel combusted for electricity generation, which is the primary source of CO₂ emissions in the United States. Understanding how electricity is made and some of the reasons for this significant contribution will help our citizens appreciate the types of changes that we need to make to reduce our emissions to mitigate climate changes.

Key Concepts and Vocabulary

Greenhouse gas: A greenhouse gas (GHG) is a gas in an atmosphere that absorbs and emits radiation within the thermal infrared range. This process is the fundamental cause of the greenhouse effect. The primary greenhouse gases in the Earth's atmosphere are water vapor, carbon dioxide, methane, and nitrous oxide.

Electric energy: Electrical energy (electricity) refers to the flow of power or the flow of charges along a conductor. Electrical energy is a secondary source of energy, which means that we obtain electrical energy through the conversion of other forms of energy. The primary sources energy include coal, nuclear energy, natural gas, oil, the sun, wind, etc. The primary sources from which we create electrical energy are classified as non-renewable or renewable forms of energy. Electrical energy however is neither non-renewable or renewable.

Emissions factor: An emission factor is the relationship between the amount of pollution produced and the amount of raw material processed or number of product units produced. For example: GHG emissions per kWh electricity generated.

Steam turbine: A steam turbine is a mechanical device that extracts thermal energy from pressurized steam, and converts it into rotary motion. It is one of the critical processes in most electricity power plants to transfer the heat energy from fossil fuel combustion into mechanical energy required to move the magnets and copper coils that comprise the electric generator.

Energy efficiency: Energy conversion efficiency is the ratio between the useful output of an energy conversion machine and the input, in energy terms. The useful output may be electric power, mechanical work, or heat. Increasing energy efficiency essentially enables you to do more with less energy input.

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**Lifecycle emissions:** A product or processes’ lifecycle includes all of the steps from extracting raw materials to make the product, manufacturing of the product and all of its component parts, the product use and ultimate disposal or other end-of life fate. Lifecycle emissions include emissions (pollutants) for all of these processes summed together. We often associate emissions with just one step (e.g., automobile tail pipe emissions) rather than also considering the emissions for making the fuel and automobile (etc.) as well.

**Background Information**

Electricity generation contributes nearly 40% of the total GHG emission generated in the United States\(^2\) and thus deserves significant attention and understanding if our Nation sets policies for reducing GHG emissions to help mitigate global climate change. Coal combustion, which accounts for 45-50% of our national electric energy generation, contributes over 81% of the GHG emissions from electric power generation.\(^3,4\)

![Relative Contribution by Fuel Type](image)

There is a variety of reasons for the high CO\(_2\) emissions from coal. Most importantly, a greater fraction of the mass of coal is comprised of carbon atoms. Thus, when it is combusted, there is more carbon per mass of fuel that can be oxidized to CO\(_2\). Another contributing factor is the efficiency of some of our older coal power plants. With efficiencies on the order of <30-40\%, that means only about one-third of the energy value of coal is converted to electricity that leaves the power plant. Another 10\% of that is lost through the electricity transmission and distribution system before it gets to your home. Inefficiencies in the electricity generation process are primarily attributed to unrecoverable heat energy from the combustion process and friction.

The figure below illustrates the primary steps in the production and use of electricity from coal resources. Each of the major processes in this sequence is termed a “stage” in the overall lifecycle process of creating and using electricity from coal. The primary steps include mining and processing coal to prepare it for combustion, combustion of coal to make steam, passing the steam through a turbine to rotate it (and convert the heat energy of the steam into mechanical energy), and finally the rotation of the generator, which is comprised of copper coils and magnets, to induce an electrical current.

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GHG emissions are typically expressed as emission factors in units of mass of GHGs emitted per unit of electric energy produced (e.g., g CO₂ eq./kWh or metric ton (Mg) CO₂ eq./MWh). The figure below presents some emission factors for electricity generation.⁵ These include both those related to the actual fuel combustion (stack emissions) as well as other emissions associated with equipment and facility construction and operation, and fuel mining, processing and transportation. These other emissions stem from other stages in the lifecycle process of energy resource extraction through conversion to electricity. A couple of key points can be made about these values:

- Coal emissions are much higher than any other energy resource used for electricity, including other fossil fuels.
- There are a range of values for each of the primary sources due to different technologies used for combustion and electricity generation, different characteristics of fuels (e.g., lignite versus anthracite coal), and differences in the assumptions made to estimate these emission factors.
- There are GHG emissions even for renewable energy resources, although most are orders of magnitude lower than for the fossil fuels.

Electricity generation in the United States is broken into 26 different regions. For

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example, most of New York State is in the upstate region (NYUP), but New York City (NYCW) and Long Island (NYLI) have their own regions. Within each of these regions, the total electricity generation and total GHG emissions are averaged to provide regional emission factors for the overall mix of electricity. This is often also done at the state level.

Table 1 provides values for regional emission factors that are averaged over all types of electricity generation. Emission factors for CO$_2$ vary by more than a factor of three among the regions. New York State, for example, is well below the national average. These emission factors were compiled by the U.S. EPA’s eGrid program. They only include combustion related (stack) emissions, not total lifecycle emissions.

<table>
<thead>
<tr>
<th>eGRID subregion (see map above)</th>
<th>Carbon dioxide (kg CO$_2$/MWh)</th>
<th>Methane (kg CH$_4$/MWh)</th>
<th>Nitrous oxide (kg N$_2$O/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMPA</td>
<td>865</td>
<td>0.0107</td>
<td>0.0131</td>
</tr>
<tr>
<td>SPNO</td>
<td>817</td>
<td>0.0096</td>
<td>0.0133</td>
</tr>
<tr>
<td>SRMW</td>
<td>808</td>
<td>0.0093</td>
<td>0.0134</td>
</tr>
<tr>
<td>RFCW</td>
<td>704</td>
<td>0.0083</td>
<td>0.0118</td>
</tr>
<tr>
<td>SRTV</td>
<td>700</td>
<td>0.0090</td>
<td>0.0116</td>
</tr>
<tr>
<td>HIMS</td>
<td>610</td>
<td>0.0614</td>
<td>0.0099</td>
</tr>
<tr>
<td>SRVC</td>
<td>508</td>
<td>0.0101</td>
<td>0.0087</td>
</tr>
<tr>
<td>NWPP</td>
<td>390</td>
<td>0.0074</td>
<td>0.0062</td>
</tr>
<tr>
<td>NEWE</td>
<td>376</td>
<td>0.0349</td>
<td>0.0069</td>
</tr>
<tr>
<td>NYCW</td>
<td>320</td>
<td>0.0119</td>
<td>0.0015</td>
</tr>
<tr>
<td>NYUP</td>
<td>310</td>
<td>0.0079</td>
<td>0.0045</td>
</tr>
<tr>
<td>AKMS</td>
<td>243</td>
<td>0.0103</td>
<td>0.0020</td>
</tr>
<tr>
<td>U.S.</td>
<td>587</td>
<td>0.0114</td>
<td>0.0089</td>
</tr>
</tbody>
</table>

### Instructional Strategies

This project module includes three in class activities and a homework assignment. The different activities are geared towards different age levels. Collectively, the set of activities can be used to explain electricity generation systems, their efficiency and differences in greenhouse gas generation.

<table>
<thead>
<tr>
<th>Activity appropriate for:</th>
<th>Middle school</th>
<th>High school</th>
<th>College</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy efficiency activity</td>
<td>X</td>
<td>X</td>
<td>--</td>
</tr>
<tr>
<td>Lifecycle electricity generation poster</td>
<td>X</td>
<td>X</td>
<td>X*</td>
</tr>
<tr>
<td>Review of U.S. EPA Power Profiler results</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Homework – application of electricity mix and emission factors to determine state average</td>
<td>--</td>
<td>--</td>
<td>X</td>
</tr>
</tbody>
</table>

* perhaps best without the prepared cut-outs the younger students get

### Anticipatory Set

A brainstorm about how we use energy and then specifically electric energy will get students engaged in thinking about energy overall and its split between electrical and other forms. A [powerpoint lecture](http://www.epa.gov/cleanenergy/documents/egridzips/eGRID2010V1_1_year07_GHGOuputrates.pdf) is available to introduce some of the key concepts:

- forms of energy we use and how important they are to our lives (electricity, petroleum fuel for transportation, fuel for heating, embodied energy in goods, etc.);
- major sources of energy in the U.S.;
- the importance of electricity in terms of our Nation’s total greenhouse gas emissions;

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6 U.S. EPA eGRID2010 Version 1.1,

Project module prepared for the Project-Based Global Climate Change Education Project, funded by NASA NICE. Copyright © 2011, Clarkson University, Office of Educational Partnerships, Potsdam NY.
[http://www.clarkson.edu/highschool/Climate_Change_Education/index.html](http://www.clarkson.edu/highschool/Climate_Change_Education/index.html)
• not all energy resources are equivalent – making electricity out of coal versus nuclear power (for example) has very different consequences related to GHG emissions; and,
• making electricity from fossil fuel is a complex series of steps, the sum of which is defined as the “lifecycle.” Most – but not all - of the GHG emissions from fossil fuel power plants is related to the fuel combustion.

**Procedure** This unit has three primary activities and an associated homework assignment. The selection of which activities are completed depends mostly on the age and learning level of the students. The first two activities are best completed by groups (3-4) students. The Review of the Power Profiler tool can be done individually or in pairs at a computer. An introductory **powerpoint lecture** is available to introduce aspects of the materials. Suggested timeline:

Day 1: Introduction and [energy efficiency activity](#)

Days 2-3: Create and briefly present the [lifecycle posters](#)

Day 4: Use [Power Profiler tool](#) and summarize on [worksheet](#) (assign HW if appropriate for grade level)

**Closure** The students should have mastered all of the learning objectives through the series of activities included here. A general discussion could include:

- some analysis of the relative high or low emission factors for the region your school is in (or the students’ home towns) and the implications for those differences
- Should more be done to find alternative energy resources to make electricity from?
- How can increased energy efficiency at the end-user help?
- What types of new power generation technologies should be implemented to reduce GHG emissions?

**Learning Contexts**

This unit can be used to connect science, technology and environmental science topics. There are opportunities for extensions in any of these areas. For example – more on the combustion chemical reactions for a physical science class, electricity generation technologies and alternatives in a technology class, or consequences (climate change, acid rain, etc.) for an environmental science class.

**Science Standards**

The following New York State Science Standards are supported by this module:

**STANDARD 1—Analysis, Inquiry, and Design**

Students will use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and develop solutions.

- The central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing, creative process.
- The observations made while testing proposed explanations, when analyzed using conventional and invented methods, provide new insights into phenomena.

**STANDARD 3- Mathematics**

Students will understand mathematics and become mathematically confident by communicating and reasoning mathematically, by applying mathematics in real world settings, and by solving problems through the integrated study of number systems, geometry, algebra, data analysis, probability and trigonometry.

- Students use measurement in both metric and English measure to provide a major link between the abstractions of mathematics and the real world in order to describe and compare objects and data.
STANDARD 4 - Science

Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

- Human Decisions and activities have had a profound impact on the physical and living environment.

STANDARD 6 – Interconnectedness: Common Themes

Students will understand the relationships and common themes that connect mathematics, science, and technology and apply the themes to these and other areas of learning

- Models are simplified representations of objects, structures, or systems used in analysis, explanation, interpretation, or design.

Mathematics Standards

The following National Common Core Mathematics Standards are supported by this module: [http://www.corestandards.org/the-standards/mathematics](http://www.corestandards.org/the-standards/mathematics)

Students will be able to:

G-MG.3. Apply geometric methods to solve design problems Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

N-Q.2. Define appropriate quantities for the purpose of descriptive modeling.

G-MG.3. Apply geometric methods to solve design problems

S-ID.1. Represent data with plots on the real number line (dot plots, histograms, and box plots).

(science standards pending)

Assessment

The lifecycle posters and Power Profiler worksheet can be collected and graded as part of the assessment. The college-level homework assignment also provides a means of assessing if the students understand the concepts and met the learning objectives.

Other Resources

Energy Efficiency Activity

Electricity, efficiency and emissions [powerpoint lecture](#)

Cut-outs for electricity generation lifecycle poster

U.S. EPA Power Profiler

Student worksheet for Power Profiler activity

Homework assignment - State emission factors for electricity (geared for college, perhaps also HS students)
Case Study: Does where I live make a difference in my personal GHG emissions?

The analysis of electricity generation and associated greenhouse gas emissions is completed here for upstate New York (NYUP) and Denver CO.

New York State has abundant water resources and relies heavily on major rivers (Niagara, St. Lawrence) and many smaller rivers for hydroelectric power. There are also several nuclear power plants that operate with nearly negligible greenhouse gas emissions. NYS clearly relies less on fossil fuel, especially coal, with less than 50% of the percentage that coal contributes to our National electricity mix and far less than use in Denver (Figure 1). Nuclear (~28%) and hydroelectric power (25%) are much more important in NYS. Denver is close to the coal-rich state of Wyoming.

![Figure 1: Electricity generation mix in upstate NY and Denver versus the National average](image)

These differences in the electricity generation mix show up in terms of GHG emissions. The National average (587 kg CO₂/MWh) is nearly twice as high as the NYS emissions factor (310 kg CO₂/MWh). Denver’s emission factor (865 kg CO₂/MWh) is 2.8 times as high as NYS. The U.S. Power Profiler reports CO₂ emissions from the stack. Other GHGs and lifecycle impacts are not included in these values. Because NYS electricity generation mix is relatively low on the CO₂ production scale, there could be less driving force to reduce these emissions. These state or regional values are used in most personal carbon calculators. Thus, someone in NYS who uses a lot of electricity might not see the same need to reduce their electricity consumption as someone in Colorado or Nebraska (emission factor > 800 kg CO₂/MWh), where nearly all of the electricity is generated from coal. But because NYS uses a lot of electricity as a whole, there is still a concern and still a significant need to reduce electricity related GHGs.

![Figure 2: Comparison of regional electricity emission factors for CO₂](image)
Step-by-Step

Part 1—Energy Efficiency Activity – an active group demonstration of efficiency and “losses.”

Part 2—Electricity system lifecycle posters – students use pre-made paper icons to create posters that show the lifecycle stages involved with making electricity from various energy resources.

Part 3—Power Profiler – students use an EPA tool to explore regional differences in electricity generation mixes and the associated CO2 emissions. MS students can enter their data into a table they create on paper if they do not have adequate MS Excel skills. College students (perhaps some HS students too) can do a follow up homework assignment to calculate their own values for state or regional electricity emission factors based on the specific electricity mix.

Part 1—Energy Efficiency Activity

1. Gather materials
   a. two brown paper bags for each group
   b. Styrofoam peanuts – enough to fill 1 bag for each group ~half full
   c. stop watch
   d. small scale (e.g., kitchen scale)
2. Open and distribute “Student worksheet – Energy Efficiency” file, (print or use electronic) and distribute to each student.
3. Follow instructions for completing the activity, calculating efficiency and responding to discussion questions.
4. Students submit the completed worksheet.

Part 2—Electric System Lifecycle Posters

1. Gather materials – 24” x 36” posterboard, scissors, markers, gluestick for each group
2. Open “LCA cutouts.ppt” file. Print one page of each of the electricity systems – each group can do one system. Print several copies of the general systems (transportation, transportation fuel, emissions, etc.) Note that an extensive LCA poster could include petroleum fuel for transportation and all of the petroleum extraction and processing steps. Some extra copies of the petroleum page may be warranted.
3. Students or the teacher can cut the printed pages into their individual parts.
4. Open file “Student Worksheet – Electricity Generation Lifecycle Posters” and distribute to students to guide them and as a place for them to answer discussion questions.
5. Make posters and complete discussion questions.

Part 3—Power Profiler

1. Open the student worksheet Power profiler and distribute to students electronically or on paper.
2. Create a spreadsheet to record the information from the Power Profiler. Each row will be a different location. Include columns for zipcode, city name, electricity mix (% coal, % oil, % natural gas, %nuclear, %hydro and % non-hydro renewables), emissions factor for CO2 (lb/MWh), and personal CO2 emissions.
3. Open the Power Profiler web site and review the description of this tool.
4. Enter your zipcode, click “next. If there is a choice of electricity distributors in your region, click on the one used in your town.
5. The resulting graphical display will show you the electricity mix and emissions characteristics for your home relative to the national average. Record these values in your spreadsheet.
6. At the bottom of the page, under “3. What can I do to make a difference?”, click on “My Emissions” Enter data for your own family’s electricity consumption or chose option 3, which uses an average value of 900 kWh/mo electricity. A new result window will open that estimates your annual emissions of carbon dioxide. Record this value in your spreadsheet.

7. Repeat steps 4-6 for at least 5 other locations throughout the United States. Chose locations that are far apart. Record results in your spreadsheet. If there is a particular place you want to investigate but do not know the zipcode, use the U.S. Postal Service’s web tool: http://zip4.usps.com/zip4/citytown.jsp

8. Create a second column in your spreadsheet for the CO2 emission factors in units of kg CO2/MWh. lb X 0.454 kg/lb = kg

9. Create graphs for electricity mix (bar, stacked bar or pie charts), and a bar graph for regional CO2 emission factors.

10. Complete answers in the student worksheet.

11. (optional) – Complete Emission factors homework assignment
Tools and Data

Tool - Microsoft Excel

A spreadsheet application is needed to analyze the data. Microsoft Excel is used in this chapter and is available as part of Microsoft Office.

Microsoft Corporation - [www.microsoft.com](http://www.microsoft.com)

Excel is part of the suite of Microsoft Office software. Students and educators may be able to purchase this software at a reduced cost. The Student and Home Edition is sufficient for use in this unit. [Open Office](http://www.openoffice.org) is a free software that should be compatible with this unit if MS office is not available.

Tool – U.S. EPA Power Profiler

The U.S. EPA Power Profiler ([http://www.epa.gov/cleanenergy/energy-and-you/how-clean.html](http://www.epa.gov/cleanenergy/energy-and-you/how-clean.html)) allows access to a database of electricity generation data that are used to define the mix of electricity generation facilities in different regions of the U.S. and the resulting CO₂ emission factors (lb CO₂/MWh) and total CO₂ for an average residence within the region. This tool provides a resource to explore how different the electricity mixes are across the country and the implications for these variations in terms of personal CO₂ emissions from electricity. As of June, 2011, the Power Profiler accessed the 2007 eGRID database. The eGRID database can also be accessed directly ([http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html](http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html))