Center for Renewable Energy Advanced Technological Education

Sketchbox Lesson 4: Carbon Emissions

INSTRUCTOR'S GUIDE

Grade Level: High School, Technical College, Community College
Lesson Length: 1 hour
Author: James Reichling
Created: August, 2025

Learning Goals:

- Students can explain the meaning of carbon dioxide equivalents
- Students can use the Sketchbox™ interface to model the energy use of a building and, with the results, calculate the annual carbon dioxide equivalent emissions
- Students can list several factors that affect carbon emissions that result from energy used in buildings

Technology Required:

- Internet-accessible digital device to use Sketchbox™,
  Sketchbox user account (free)

Next Generation Science Standards (https://www.nextgenscience.org/)

Content Standards

HS-LS2-7 Ecosystems: Interactions, Energy, and Dynamics
Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.*

HS-ETS1-4 Engineering Design
Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

Science and Engineering Practices

2. Developing and using models
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Lesson metatags

building design, computer model, data analysis, efficiency, electricity, energy, energy conservation, energy economics, heating and cooling, HVAC, kwh, natural gas, NG, simulation, utility rates, carbon emissions, greenhouse gas equivalents

The Activity:
This activity involves the use of a computer model that calculates the energy use for a specific building in a given location. Sketchbox™ is a user interface to the energy modeling software DOE2 that uses typical industry values to make quick energy estimates for energy use in buildings. Sketchbox™ and DOE2 use historical weather input data for the location selected in the model along with location specific CO_2 equivalent emissions data for electricity and cost data for electricity and natural gas.

Sketchbox™ has preloaded data for carbon emissions related to electricity in different locations. This carbon emissions data, along with the CO_2eq value for using natural gas, can be used to calculate the total carbon dioxide equivalent emissions attributed to the energy used to operate a building for one year. In the activity students will calculate carbon emissions for operation of a baseline building case then explore the impact of improved lighting efficiency and improved use of ventilation (demand control ventilation) on the carbon emissions. Finally, students will move the building to a location with a different electricity generating mix to explore the impact of electricity generation on carbon emissions.

Discussion ideas
Post lesson discussion questions are included with the teacher slides and copied here. Slides containing these questions also have related sample data to aid in discussion.

1. Compare the carbon reduction for the two building changes. Which is better? What other factors matter?

2. Moving the building from Chicago, IL, to Madison, WI, reduced the energy use but increased the carbon equivalent emissions. Why does this happen?

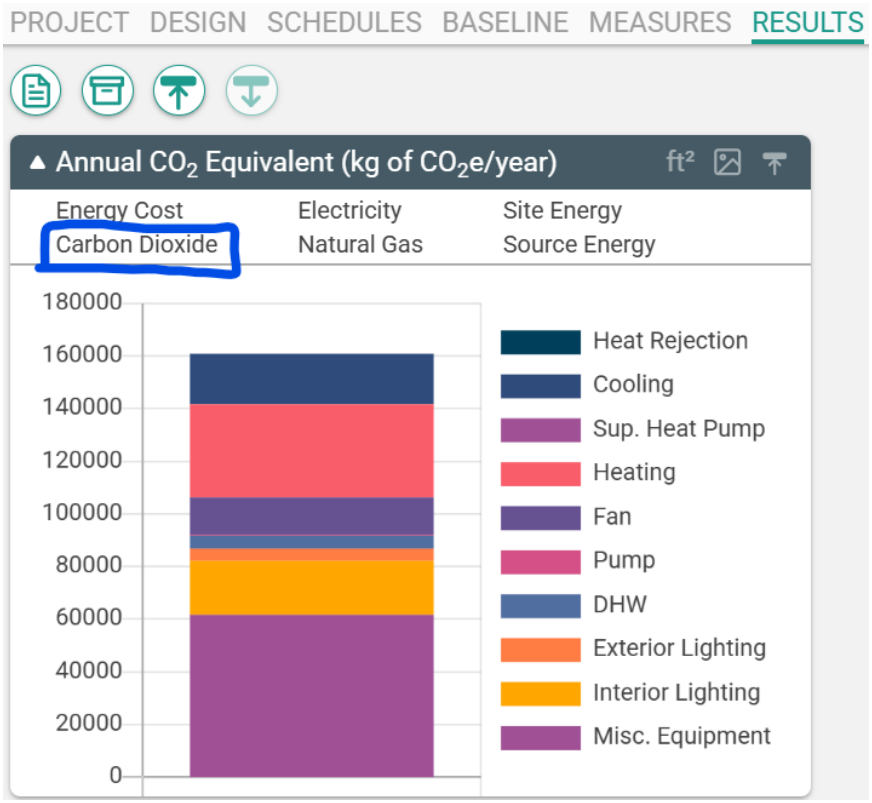
Extension activities and questions
These ideas are included in the teacher slides but copied here for reference. They are intended as additional learning activities, especially for students of student groups that complete other parts of the lessons before their peers.

Students can consider what they know about both climate and electricity generation to predict a location where the office building has lower carbon emissions then use Sketchbox to test the result

With some guidance, students can electrify the building in Chicago and examine the resulting carbon emissions

Students can explore the impact of adding solar PV to the building using the PV Watts solar photovoltaic calculator from the National Renewable Energy Laboratory: https://pvwatts.nrel.gov/

Students can use other displays in the results tab to explore which building energy uses account for the most carbon emissions



Copy of student handout with sample responses begins on next page

CREATE	Center for Renewable Energy Advanced Technological Education	Name: _____ Date: ____ / ____ / ____ Class Hour: ____

SKETCHBOX™ LESSON 4_v1.01:
Carbon Emissions

Student Activity and Response Guide

Introduction

Energy use in buildings results in large amounts of carbon dioxide emissions. This is especially true when natural gas is used to heat space or hot water and for most of the electricity currently produced in the United States. Making a building more energy efficient is an excellent way to reduce these emissions. Since electricity generation is slowly transitioning to low-carbon energy sources some building systems that burn natural gas or other hydrocarbon fuels are being replaced with electric systems that can do the same functions, a change called electrification. Examples of this are to use a heat pump for space heating and cooling or on-demand electric water heaters.

Emissions are often reported as carbon dioxide equivalents

While burning carbon-based fuels creates carbon dioxide, other emissions also cause environmental harm. For example, nitrogen oxides and unburned natural gas also negatively impact the environment. To estimate the total impact of emissions from a particular process values are often reported as kilograms of carbon dioxide equivalents, written as kg-CO_2e. This value includes carbon dioxide and a weighted contribution for other pollutants, some of which are more environmentally damaging, per kilogram, than carbon dioxide.

Sketchbox calculates carbon emissions results

Carbon emissions from generating electricity vary from by location due to the primary energy source (e.g. wind, solar, natural gas, coal, biomass, nuclear). For example, in Illinois Sketchbox models carbon emissions for electricity as 0.371 kg-CO_2 eq for each kilowatt hour (kWh) while for neighboring Wisconsin the value is 0.633 kg-CO_2 eq / kWh. The first step in reducing carbon emissions is usually to use less energy through energy efficient building construction, careful siting, appropriate scheduling, and use of energy efficient lights and equipment. Every kWh of electricity or therm of natural gas that is not needed will account for zero kg-CO_2 eq per kWh or therm, the best we can do! After that, carefully choosing heating and cooling systems may also have an impact.

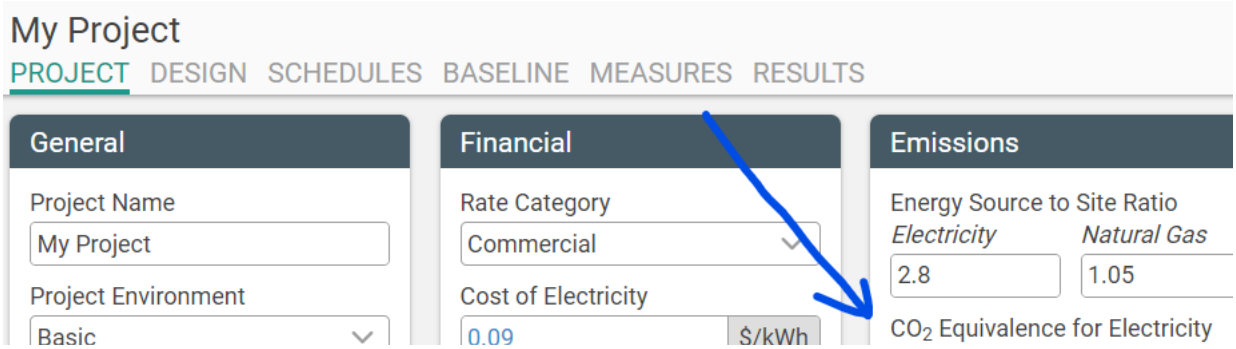
Calculating carbon emissions

1. Access the web address: https://www.sketchbox.io/login

2. Login to sketchbox using your account.

3. When sketchbox opens use the "project" tab to name your project. Then, record the CO_2 equivalence for electricity and natural gas from the "emissions" table. These values are specific to the location, in this case Chicago.

Electricity (kg of CO_2e/kWh): * **0.371** Natural gas (kg of CO_2e/kWh): * **5.3**



4. Switch to the design tab to note the building type and area, but you do not need to make any changes. We will model a medium office building.

5. Switch to the results tab and fill in the annual electric and natural gas consumption in the top row of table 1 (located below).

Table 1

Building model	Annual electric consumption (kWh)	Annual natural gas consumption (therm)	Annual emissions Kg-CO_2e
Baseline	* 325,890	* 7542	* 160,878
Energy efficient lights	* 301,831	* 7886	* 153,775
Demand control ventilation	* 323,180	* 6234	* 152,940
Move to Madison, WI	* 319,475	* 7464	* 241,787

6. With the electricity (kWh) and natural gas (therm) values just recorded it is possible to calculate the total annual carbon emissions for the building. Multiply the annual

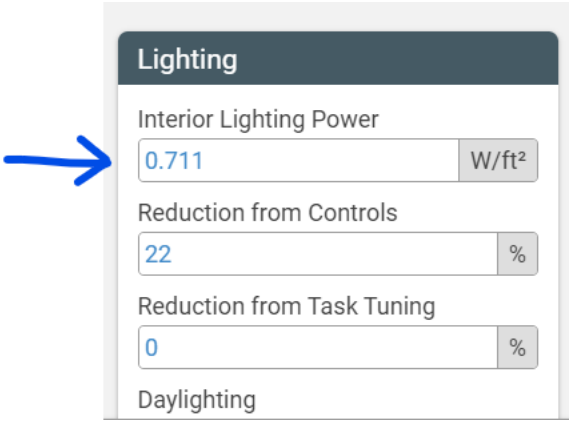
electric consumption (kWh) by the kg-CO_2e/kWh value you recorded for electricity in step 3. Record the result here: * **325,890 kWh * 0.371 Kg-CO_2e/kWh = 120,905 Kg-CO_2e**

7. Multiply the annual natural gas consumption from table 1 by the kg-CO_2e/therm value from step 3 and record the result here: * **7542 therm * 5.3 Kg-CO_2e / therm = 39,973 Kg-CO_2e**

8. Add together the CO_2e emissions totals from steps 6 and 7 and record that result in the top row of table 1 in the annual emissions column. This number is the total amount of carbon dioxide equivalent emissions produced by the energy used for the building over a typical year. In the next steps we will explore how this emission value can be reduced.

9. Interior lighting power describes how much electric power is needed, per square foot, to provide light for tasks typically done in a building. This value can vary a lot based on how much light is needed in a particular type of building and with the type of lighting technology. More efficient lighting may cost more to install, but the extra cost may more than pay for itself in energy savings.

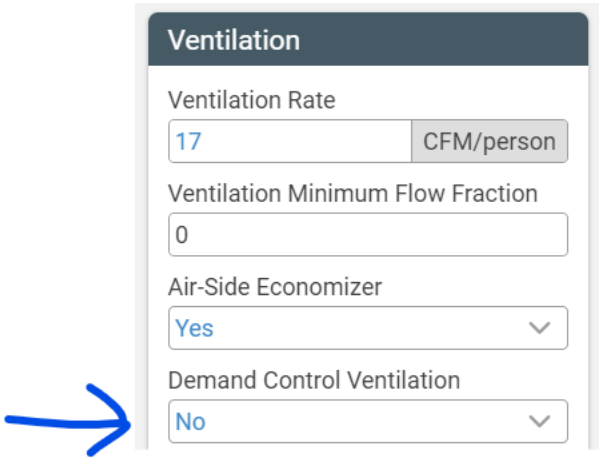
10. Switch to the baseline tab and find the lighting section in the bottom row (see image below). Reduce the interior lighting power from 0.711 to 0.45 W/ft^2.



11. Switch back to the results tab and add the new values for electricity and natural gas consumption to the second row of table 1. Then, calculate the kg-CO_2e value in the same way you did for the first row.

12. Another way to reduce the energy use by buildings is to only provide fresh air when it is needed to meet the needs of building occupants. For example, it saves energy to not provide fresh air for a room if no one is in the room. This feature of building controls is called demand control ventilation.

    Switch to the baseline tab and change the interior lighting power back to 0.711 W/ft^2. Then, find the ventilation section in the bottom row and change the "demand control ventilation" setting from no to yes.



13. Change to the results tab and record electricity and natural gas consumption values in the third row of table 1. Then, calculate the annual carbon emissions as you did for the previous rows.

14. Comment on the carbon emission reductions from these two strategies (efficient interior lighting, demand control ventilation). Is the carbon emissions savings significant? What barriers might prevent these changes from being put in place?
    * **The carbon emissions are a little over four percent for each of these changes, together that is getting close to ten percent. The barrier might be cost, but if the building is designed well the cost for appropriate lighting might not be too significant, it may even save money in lighting installation. The demand control ventilation may be more expensive depending on the cost of the sensors and controls needed for this change.**

15. As mentioned, carbon emissions from electricity depend on the primary energy source used to generate electricity. In Illinois a substantial amount of electricity is generated by nuclear power plants so carbon emissions for electricity in Illinois are relatively low. In neighboring Wisconsin there is less nuclear electricity and more generation from coal and natural gas.

    Switch to the project tab and change locations from Chicago, Illinois to Madison, Wisconsin. The natural gas kg-CO_2e/therm value is the same as in step 3, but the electricity value will be different. Record the new values.

Electricity (kg of CO_2e/kWh): * **0.633** Natural gas (kg of CO_2e/kWh): * **5.3**

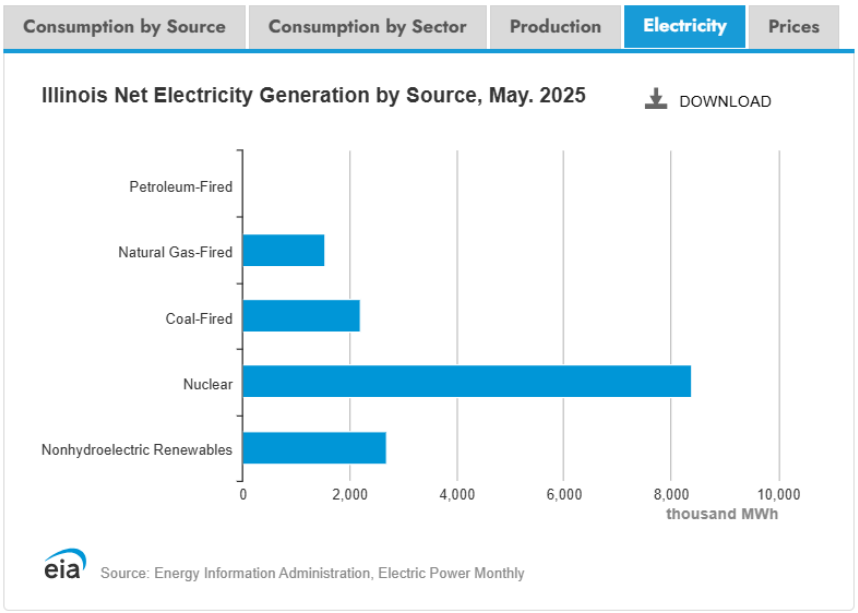
16. Return to the results tab and use the new annual summary values for electricity and natural gas for the last row in table 1. Then, calculate the final annual carbon emissions value.

17. What do you notice about the carbon emissions for the building in Madison compared to Chicago? Summarize the reasons you believe cause this difference.
    * **In Madison the energy utilization is less but the emissions are greater. This is due to a different fuel generating mix for electricity in Wisconsin (more coal and natural gas) than in Illinois (less coal and natural gas, more nuclear).**

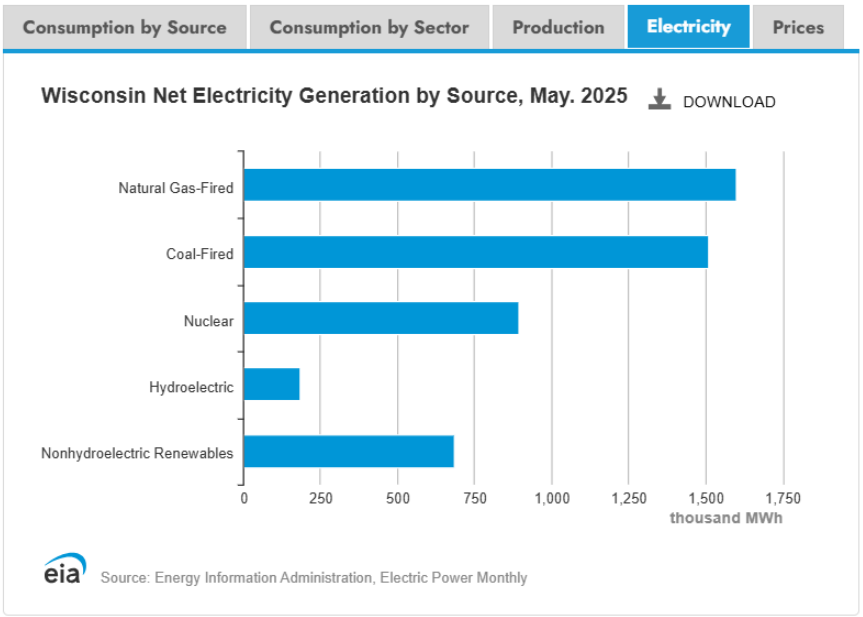
Additional resources for this topic
The U.S. Energy Information Administration provides energy profiles for every state. These can be accessed from the link below and selecting the "electricity" tab shows a detailed chart of the primary energy sources used for electricity generation in that state.

EIA state energy profiles:
https://www.eia.gov/state/

Example for Illinois:



Compare to Wisconsin:



There are also many green building ideas and strategies included in the LEED process, Leadership in Energy and Environmental Design, from the U.S. Green Building Council: https://www.usgbc.org/leed