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By Andrew Jones, Yasmeen Zahar, Ellie Johnston, John Sterman, Lori Siegel, Cassandra Ceballos, Travis Franck, Florian Kapmeier, Stephanie McCauley, Rebecca Niles, Caroline Reed, Juliette Rooney-Varga, and Elizabeth Sawin

Last updated September 2021

The En-ROADS Climate Solutions Simulator is a fast, powerful climate simulation tool for understanding how we can achieve our climate goals through changes in energy, land use, consumption, agriculture, and other policies. The simulator focuses on how changes in global GDP, energy efficiency, technological innovation, and carbon price influence carbon emissions, global temperature, and other factors. It is designed to provide a synthesis of the best available science on climate solutions and put it at the fingertips of groups in policy workshops and roleplaying games. These experiences enable people to explore the long-term climate impacts of global policy and investment decisions.

En-ROADS is being developed by Climate Interactive, Ventana Systems, UML Climate Change Initiative, and MIT Sloan.

This guide provides background on the dynamics of En-ROADS, tips for using the simulator, general descriptions, real-world examples, slider settings, and model structure notes for the different sliders in En-ROADS.

In addition to this User Guide, there is an extensive Reference Guide that covers model assumptions and structure, as well as references for data sources.

Please visit support.climateinteractive.org for additional inquiries and support.
1.1 About En-ROADS

En-ROADS is a powerful simulation model for exploring how to address global energy and climate challenges through large-scale policy, technological, and societal shifts. With En-ROADS you can create scenarios that focus on how changes in taxes, subsidies, economic growth, energy efficiency, technological innovation, carbon pricing, fuel mix, and other factors will change global carbon emissions and temperature.

En-ROADS is designed to be used interactively with groups where it can be the basis for scientifically rigorous conversations around addressing climate change. This makes it ideal for decision-makers in government, business, and civil society; or for anyone who is curious about the choices of our world. Climate Interactive provides extensive materials to support people in leading activities with En-ROADS that range from policy workshops to roleplaying games.

Relative to many global energy and climate system models, En-ROADS returns results in a few seconds, is transparent in its mathematical logic, and allows you to interactively test hundreds of factors. En-ROADS complements the other, more disaggregated models addressing similar questions, for example, those in the EMF-22 suite. These larger disaggregated models are used for data and calibrating results in En-ROADS.

En-ROADS stands for “Energy-Rapid Overview and Decision-Support.” Led by the team at Climate Interactive, En-ROADS has benefited from a close collaboration between Climate Interactive, Tom Fiddaman of Ventana Systems, Prof. John Sterman of MIT Sloan, and Prof. Juliette Rooney-Varga of UMass Lowell’s Climate Change Initiative. En-ROADS is an extension of the award-winning simulator C-ROADS, which thousands have used to assess national and regional greenhouse gas emission reduction pledges and lead climate negotiation exercises. Both tools were developed using the system dynamics modeling approach and draw on the MIT PhD theses of Dr. John Sterman and Dr. Tom Fiddaman.

The model emphasizes the system-wide interactions of policies. Behind the simulation is an extensive study of the latest research literature on factors such as delay times, progress ratios, price sensitivities, historic growth of energy sources, and energy efficiency potential. This enables En-ROADS to reveal the dynamic interactions between different levers, such as how energy efficiency affects renewable energy, and which feedback loops are most significant.

For those familiar with C-ROADS, the distinction between the two is that C-ROADS focuses on how changes in national and regional emissions could affect global carbon emissions and climate outcomes, while En-ROADS focuses on how global changes in energy, economics, and public policy could affect global carbon emissions and climate outcomes.

Please visit support.climateinteractive.org for additional inquires and support.
1.2 En-ROADS Tutorial

En-ROADS is designed to be easy to use. You can watch this 20-minute introductory video tour of En-ROADS. We encourage you to explore all the features of En-ROADS by clicking around. Here are some key features of En-ROADS:

1.2.1 Graphs

There are almost 100 output graphs available in En-ROADS. They show data from different parts of the global energy and climate system, and update as you move sliders within En-ROADS.

A. **Select graphs** – When you first open En-ROADS, you see the two default graphs. You can select from the full list of graphs by clicking the title of the left or right graph. You can also select from the Graphs menu from the top toolbar.

B. **More info** – For more information about a graph and what it shows, select the triangle icon to the left of the graph title.

C. **Copy graph data** – Copy the graph data to your clipboard using the copy icon on the top right side of a graph.

D. **Shortcut to popular graphs** – You can quickly jump to a selection of the most commonly used graphs from the “Show miniature graphs” icon on the top toolbar. You can click any of these miniature graphs to switch to that graph in the main graph view.

E. **View larger graphs** – If you want to expand one of the graphs into a separate window, you can access our “Large Left Graph” or “Large Right Graph” feature from the View menu in the top toolbar.

1.2.2 Sliders/Actions

There are 18 sliders representing different actions you can test in the En-ROADS simulator. Click the title of the slider or the three dots on the right of each slider to access detailed slider settings:

A. **A description of the overall slider** - This description provides further detail about the particular solution.

B. **More control of the main slider** - You'll see the units associated with the slider and the numeric values of points along the slider. You can directly input numeric values to set the slider level to a specific value of your choice (within range). Scroll down to change and explore the related sliders. Click on the triangle to the left of each slider title to see a brief description of the slider.
C. **Related graphs** - In the right panel, you’ll see a graph relevant to the main slider as well as a choice of additional Related Graphs. These are useful to reference in order to examine the changes that occur from moving the sliders in this view. Select from the dropdown list of Related Graphs to view other graphs. You will still be able to see your slider moves impact the main graphs as well.

D. **Help** - You can access more detailed information about the slider through the information button. This is the same information that is found for this topic in the En-ROADS User Guide.

### 1.2.3 Top Toolbar Features

Many useful features are just a click away from the top toolbar on En-ROADS. Here are some of the features that you can access.

A. **Share Your Scenario** – You can share your unique scenario link to others. Others can open your En-ROADS scenario with all the settings you have chosen and the last main graphs you viewed. You can then share your scenario to social media channels. Grabbing the link from your browser’s URL bar will also work, however, your last viewed graphs will not be captured.

B. **Replay Last Change** – This is a fun feature to rapidly replay your last change several times. This feature assists you in examining how the different parts of the system responded to your action by giving you more time to look for changes across related graphs. You can also use the other controls to Undo or Redo your last action (located left of the “replay last change” control on the top toolbar).

C. **Assumptions** [under the “Simulation” menu] – Access and change important assumptions driving the En-ROADS model.

D. **U.S. Units** [under the “View” menu] – Change from metric to U.S. units.

E. **Actions and Outcomes** [under the “View” menu] – This list summarizes the total actions and key climate outcomes from your scenario.

F. **Related Examples** [under the “Help” menu] – This list shares common examples of topics and solutions related to each of the 18 sliders. This is helpful when you need to quickly pull up a list of examples which relate to each of the sliders.

Please visit support.climateinteractive.org for additional inquiries and support.
1.3 En-ROADS Structure

A simple way to think about the structure of En-ROADS is by considering the drivers of climate impacts. In the simulator, the concentration of greenhouse gases drives up global temperature, which leads to various impacts (e.g., sea level rise and ocean acidification).

The concentration of greenhouse gases in the atmosphere is driven by four main sources:

1. **Energy CO2 Emissions** from burning coal, oil, gas, and biomass. CO$_2$ emissions from energy currently comprise about 65% of greenhouse gas emissions.

2. **Land Use CO2 Emissions** such as forestry and land use change. CO$_2$ emissions from land use currently comprise about 7% of greenhouse gas emissions.

3. **Carbon Dioxide Removal** approaches that pull carbon dioxide out of the atmosphere and store it in plants, soils, or underground leading to a decrease in CO$_2$ concentrations.

4. **Other Greenhouse Gas Emissions** such as methane, N$_2$O, and F-gases. Non-CO$_2$ emissions currently comprise about 28% of total greenhouse gas emissions.

Going further, CO$_2$ emissions from energy are driven by four factors, which is known as the “Kaya Identity”. Population, consumption (GDP/capita), energy intensity (energy use per dollar of GDP), and carbon intensity (CO$_2$ emissions per unit of energy) are all multiplied together and the result is overall energy CO$_2$ emissions. In this way, at a high level, reducing CO$_2$ emissions is about four things: fewer people, less consumption, more efficiency, and less high-carbon energy supplies.
1.4 Kaya Graphs

This view shows the drivers of growth in carbon dioxide emissions from energy, which reflects about two-thirds of all greenhouse gas emissions.

It is called the “Kaya” view because of the equation below, created by Yoichi Kaya:

\[
g_{\text{Global Population}} \times \text{GDP per Capita} \times \text{Energy Intensity of GDP} \times \text{Carbon Intensity of Energy} = \text{CO}_2 \text{ Emissions from Energy}
\]

Here is one way to understand its trends over time:

**Global Population** is growing—we are currently approaching 8 billion people—and anticipate growth to 11 billion by the end of the century, according to UN projections. The rate of growth is slowing over time as people have smaller families.

**GDP per Capita** is growing steadily per year, and we assume it will continue, mostly as people in rapidly developing countries such as China, India, South Africa, Mexico, Brazil, and Indonesia attain higher standards of living.

**Energy Intensity of GDP** is decreasing over time, due to the world economy becoming more efficient, or using less energy per unit of economic output. Technologies are improving—for example, more efficient cars, buildings, and machines—and economies are shifting from manufacturing to services. The product of global population, GDP per capita, and the energy intensity of GDP is the total amount of energy used by the global economy.

**Carbon Intensity of Final Energy**, the amount of carbon dioxide emitted by energy use, is expected to slightly decline over time. Overall, this downward trend in carbon intensity is attributed to the gradual shifting away from fossil fuels and towards low-carbon energy sources.

**Carbon Dioxide Emissions from Energy** is the result of all four factors multiplied together, and you can see that in the Baseline scenario emissions are growing. As the level of carbon dioxide in the atmosphere correlates with temperature, an increased concentration of carbon dioxide in the atmosphere leads to an increase in global temperatures.

These factors explain in simple terms, why emissions are increasing in the Baseline scenario. Improvements in efficiency and decarbonization are not yet keeping up with the strong growth in population and consumption.
1.5 Background on En-ROADS Dynamics

As you use En-ROADS, pay attention to when and how much slider adjustments result in departures from the Baseline scenario. Ask your audience to reflect on why this happened to illuminate thinking about the dynamics of the climate and energy system that En-ROADS simulates.

Most of the dynamics in En-ROADS can be answered by these explanations:

1.5.1 1. Drivers of the Baseline Scenario

To gain a deeper understanding of the model’s behaviors, it is important to comprehend what factors drive the Baseline scenario.

Drivers of Growth

A challenge to limiting future warming in this simulation is the powerful growth in global GDP, which is population multiplied by GDP per person. Energy efficiency and changes to the fuel mix can help reduce energy emissions, but their success is dampened by the steady growth in GDP. Recognizing this fact leads many participants to explore different futures for population (for example, by empowering women in developing countries, which could lower population growth) and economic growth measured in GDP per person (for example, by finding ways to meet economic needs without increasing consumption).

This addresses questions such as:

- “We’ve done a lot in energy efficiency and clean energy – why haven’t emissions reduced substantially enough?”

To illustrate this point: See the Kaya Graphs view below for a low emissions scenario with increased energy efficiency and a transition to low carbon energy sources. Even though Energy Intensity of GDP improves, and the Carbon Intensity of Energy decreases as well, Global Population and GDP per person continue to grow.

Non-CO2 Emissions Affect Temperature Significantly

Methane, N₂O, and the F-gases are controlled by the Methane & Other slider. Adjusting this has a large impact on temperature. This implies significant changes in livestock management and consumption, waste management, fertilizer use, and industry. These emissions currently make up around 28% of total greenhouse gas emissions.

Addresses questions such as:

- “We’ve done a lot in energy – why haven’t we solved the climate crisis?”

To illustrate this point: See the “Greenhouse Gas Net Emissions by Gas – Area” and “Greenhouse Gas Net Emissions” graphs and adjust the Methane & Other slider. See the scenario below – highly reducing Methane & Other emissions achieves a significant reduction in 2100 temperature.
1.5.2 1. Complex Interactions Between Competing Energy Supplies and Demand

Economies of Scale and Learning

Costs of energy supplies such as renewables fall as cumulative experience is gained through a learning feedback loop, also known as “economies of scale.” Every doubling of cumulative installed capacity of renewables reduces costs by around 20%, creating a reinforcing loop (this is known as the “progress ratio”). Increasing the capacity (1) and installation (2) of new energy sources leads to increased learning (3), a decrease in price (4), increasing the attractiveness of renewables (5) and therefore even greater capacity and installations:

This addresses questions such as:

• “Why should we have hope?”
• “How can we afford a transition to a low-carbon economy?”
• “Aren’t the costs of renewables prohibitive?”
To illustrate this point: Look at the “Renewables Primary Energy Demand” graph in a scenario in which Renewables are subsidized. It sparks an initial exponential growth that is driven and sustained by the reinforcing learning loop figure shown above.

Delays and Capital Stock Turnover

New energy sources (e.g., renewables and new zero-carbon energy sources) take decades (not years) to scale up sufficiently to compete with coal, oil, and gas globally. One of the main sources of these delays is that new energy infrastructure is only built when old infrastructure retires or there is a need to meet increased energy demand. Only about 6% of all the world’s energy infrastructure changes each year, since infrastructure like coal-fired power plants and oil refineries can be used for 30 or more years. So while new zero-carbon energy sources may make up the majority of the market share of new energy capital, it will take many years for the old capital to turn over and be retired. The climate is only helped when coal, oil, and gas is retired away, and in the absence of other interventions, that amount is relatively small — approximately 3% per year.

This addresses questions such as:

• “Why doesn’t subsidizing renewables, nuclear, or a new zero-carbon energy source help avoid more warming?”

This dynamic is also relevant to increasing energy efficiency, however, energy-using capital such as vehicles, buildings, and industry, has an average lifetime that is much shorter (10-15 years). One can promote increases to energy efficiency of new cars immediately, for example, but the average energy efficiency of all the cars takes decades to improve since it takes time for all the old inefficient cars to be taken off the road.

To illustrate this point: Move the New Zero-Carbon slider to huge breakthrough. Examine the “Global Sources of Primary Energy” graph and notice that, even as low-carbon sources grow, it takes several decades before enough fossil fuel capacity retires away to make much of an impact. Notice that coal, oil, and natural gas grow steadily through the 2020s and 2030s and it takes time for greenhouse gas emissions to depart from the Baseline scenario.
Implications of this dynamic: Policies that merely promote alternatives to fossil fuels take several decades to reduce carbon dioxide emissions — the existing infrastructure takes a long time to retire away. Thus, meeting climate goals also requires direct disincentives to building and using fossil fuel infrastructure.

**Price and Demand Effects**

Energy demand falls if energy prices rise, and demand increases if prices fall. The first dynamic is evident when carbon prices increase. The second dynamic occurs when zero-carbon energy such as renewables or a new zero-carbon energy source are either subsidized or experience a breakthrough in cost improvement.

While subsidizing low-carbon energy supplies such as Renewables, watch Final Energy Consumption increase. Inexpensive wind and solar spreading around the world decreases overall energy prices and boosts energy demand up:

On the other hand, implementing a carbon price causes energy costs to increase and consumption to decrease:

**Crowding Out or Squeezing the Balloon**
Many assume that if the world promoted several long term zero-carbon energy sources such as nuclear, wind, and solar, their contribution to carbon mitigation would be additive. Instead, they actually compete. More of one, less of the other.

This addresses questions such as:

- “Why didn’t it help to have a breakthrough in a new zero-carbon energy supply in this renewable-dominated scenario?”

To illustrate this point: See the “Global Sources of Primary Energy” graph in the three scenarios below. In the first graph, we subsidize renewables alone; in the second, there is a breakthrough in a new zero-carbon energy supply; in the third graph, we see both a renewables subsidy and a new zero-carbon breakthrough.

In the following scenario, a high Renewables subsidy leads to a 0.2 degree Celsius reduction in temperature:

A huge breakthrough in New Zero-Carbon also leads to a 0.2 degree Celsius reduction on its own:

When combined, instead of seeing an additive 0.4 degree Celsius reduction, we only see a 0.3 degree reduction in temperature due to the energy supplies competing with each other for market share:
1.5.3 3. System Dynamics of the Climate

Bathtub Dynamics - Temperature and CO2 Concentrations Seem Weakly Responsive to CO2 Emissions

Emissions must fall significantly just to change the growth in temperature and CO2 concentrations slightly. This counterintuitive dynamic is an important feature of the carbon and climate system. A short explanation for this dynamic would include the fact that the momentum in the carbon cycle and the climate lead to long delays between emissions and temperature.

This addresses questions such as:

- “Emissions are stabilized, so why is temperature or CO2 concentration still going up?”

To illustrate this point: See the “CO2 Emissions and Removals” and “CO2 Concentration” graphs in a scenario where CO2 emissions stabilize. Even though CO2 emissions (in red below) have flattened, CO2 concentrations (in blue on the right below) continue to increase:

Similarly, in a much more stringent scenario where CO2 concentration stabilizes, temperature change continues to increase:

To understand more about stocks, flows, and the bathtub framing below, check out our Climate Leader learning series.
1.6 Coal

Discourage or encourage mining coal and burning it in power plants. Coal is the most harmful fossil fuel in terms of carbon emissions, as well as in air pollutants that cause severe health impacts. It is a dominant source of energy globally, however, because it is relatively inexpensive to mine and transport.

1.6.1 Examples

- Government policies that phase out power plants or make them more expensive in any way, such as taxes on coal.
- Financial services industry (e.g. banks) or global development institutions (e.g. World Bank) limiting access to capital for new coal mining, refining, and power plant infrastructure.
1.6.2 Big Messages

- Discouraging coal is a high leverage strategy for reducing future temperature change. It keeps coal in the ground, increases the cost of energy, and reduces energy demand.
- Discouraging coal also improves public health and saves medical costs through improved air quality.

1.6.3 Key Dynamics

- When coal is discouraged, by taxing it, watch the brown area of Coal go down in the “Sources of Primary Energy” graph. It is one of the most sensitive energy supplies to any increase in cost. Unlike oil, it can often be substituted for natural gas and renewables.
- Taxing coal also reduces energy demand (see graphs “Final Energy Consumption” and “Cost of Energy”). When energy prices are higher, people tend to use energy more efficiently and conserve energy. However, tax policies must be implemented with considerations for poor and working-class communities who can be harmfully impacted by high energy prices.

1.6.4 Potential Co-Benefits of Discouraging Coal

- Reduced air pollutants from coal burning improves air quality and health outcomes for surrounding communities.
- Less coal mining reduces heavy metal drainage and waste from mine sites which improves water quality and helps protect wildlife habitats, biodiversity, and ecosystem services.

1.6.5 Equity Considerations

- Taxing coal can raise energy costs for households and businesses that rely on coal for energy needs.
- Low-income communities often suffer the worst health outcomes yet make up the majority of individuals who produce coal. Providing pathways for these people to find new jobs will be essential.

1.6.6 Slider Settings

The following table highlights the numerical ranges for the labelled input levels of the Coal slider. Each of the energy supply sliders is set to reflect a similar percentage cost increase or decrease for each input level.

<table>
<thead>
<tr>
<th>Change in price per ton of coal equivalent (tce)</th>
<th>very highly taxed</th>
<th>highly taxed</th>
<th>taxed</th>
<th>status quo</th>
<th>subsidized</th>
</tr>
</thead>
<tbody>
<tr>
<td>+$110 to +$40</td>
<td>+$40 to +$20</td>
<td>+$20 to +$6</td>
<td>+$6 to -$6</td>
<td>-$6 to -$20</td>
<td></td>
</tr>
</tbody>
</table>

| Cost increase or decrease | +200% to +60% | +60% to +30% | +30% to +10% | +10% to -10% | -10% to -30% |

1.6. Coal
1.6.7 Model Structure

The cost of coal affects three significant decisions regarding energy infrastructure:

1. Investment in new capacity (whether or not to build new processing and power plants);
2. Use of capacity (whether to run existing plants);
3. Retirement of capacity (whether to keep plants longer or shorter than the average of ~30 years).

1.6.8 Case Studies

United States: Replacing all coal-powered electricity in the US with solar power could save 52,000 lives per year, which is more than the number of people employed by the coal industry today.  

United States: The total cost of reliance on coal to the US economy is estimated to be $344 billion per year. Of that cost, $187B is from air pollution, $74.6B is from public health effects in Appalachia, and $61.7B from climate damages.  

India: A one gigawatt increase in coal-fired capacity corresponds to a nearly 15% increase in infant mortality in areas close to coal power plants. The effect was largest for older plants, plants in areas with relatively higher pollution levels, and plants burning domestic rather than imported coal.

1.6.9 FAQs

How can I directly force deeper reductions in coal use? Consider selecting the “Stop building new coal infrastructure” switch in the advanced view, and changing the “% Reduction in coal utilization” slider.

Please visit support.climateinteractive.org for additional inquiries and support.

1.7 Oil

Discourage or encourage drilling, refining, and consuming oil for energy. Oil is a fossil fuel that is used widely in cars, ships, and planes; it is also used for industry, heating, and electricity. Access to oil has sparked major conflicts, and oil spills threaten ecosystems and water quality.

1.7.1 Examples

- Governments imposing limits on oil drilling and exploration, removing subsidies, and taxing oil.
- Universities, corporations, and individuals divesting from oil companies.
- Financial services industry (e.g., banks) or global development institutions (e.g., World Bank) limiting access to capital for exploration, drilling, refining, and delivery.

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1.7.2 Big Message

- When a steep oil tax is the only action implemented, you will not see a dramatic change in temperature, as coal and natural gas demand increases in response, offsetting any large reduction of temperature.

1.7.3 Key Dynamics

- When oil is discouraged, by taxing it, watch the red area of Oil go down in the “Global Sources of Primary Energy” graph.

- When oil is taxed, notice what happens to coal and gas in response. Unless there are restrictions on coal and gas, their demand will go up in response to expensive oil. We call this the “squeeze the balloon” problem – depressing fossil fuel emissions in one area causes them to pop up in another. Renewables are also boosted slightly, but the impact is negligible. Adding a carbon price is a good solution to the “squeeze the balloon” problem, as it addresses all fossil fuels together.

- Notice that taxing oil results in an increase in electrification of the vehicle fleet as electric powered modes of transport become more affordable in the face of higher oil prices. See this demonstrated in the “Electric Share of Final Energy-Transport” graph.

1.7.4 Potential Co-Benefits of Discouraging Oil

- A reduction in oil drilling could lead to fewer oil spills, helping protect wildlife habitats, biodiversity, and ecosystem services at production sites and along transportation routes.

- Reduced economic dependence on oil can improve national security and lower military costs.

1.7.5 Equity Considerations

- The oil industry provides many high-paying jobs for people with technical trade backgrounds. Providing pathways for these people to find new jobs will be essential.

- Oil companies wield enormous economic and political power locally and globally. In order to discourage oil, certain industry protections must be eliminated.

- There is a history of oil refineries being located in marginalized communities and companies working to avoid or limit environmental regulations.

1.7.6 Slider Settings

The following table highlights the numerical ranges for the labelled input levels of the Oil slider. Each of the energy supply sliders is set to reflect a similar percentage cost increase or decrease for each input level.

<table>
<thead>
<tr>
<th>Change in price per barrel of oil equivalent (boe)</th>
<th>very taxed</th>
<th>highly taxed</th>
<th>taxed</th>
<th>status quo</th>
<th>subsidized</th>
</tr>
</thead>
<tbody>
<tr>
<td>+$100 to +$30</td>
<td>+$30 to +$15</td>
<td>+$15 to +$5</td>
<td>+$5 to -$5</td>
<td>-$5 to -$15</td>
<td></td>
</tr>
<tr>
<td>Cost increase or decrease</td>
<td>+200% to +60%</td>
<td>+60% to +30%</td>
<td>+30% to +10%</td>
<td>+10% to -10%</td>
<td>-10% to -30%</td>
</tr>
</tbody>
</table>
1.7.7 Model Structure

The cost of oil affects three significant decisions regarding energy infrastructure:

1. Investment in new capacity (whether or not to build new drilling operations and refineries);
2. use of capacity (whether to run existing operations);
3. retirement of capacity (whether to keep infrastructure longer or shorter than the average of ~30 years).

1.7.8 FAQs

How can I directly force deeper reductions in oil use? Consider selecting the “Stop building new oil infrastructure” switch in the advanced view, and changing the “% Reduction in oil utilization” slider.

Please visit support.climateinteractive.org for additional inquiries and support.

1.8 Natural Gas

Discourage or encourage drilling and burning natural gas for energy. Natural Gas is a fossil fuel that is used for electricity, heating, and industry. When burned, it releases carbon dioxide (although less than coal and oil) and, if leaked into the air, it contains high amounts of methane. Natural gas drilling uses large amounts of water and can cause contamination.

1.8.1 Examples

- Governments implementing laws against fracking and taxes on natural gas.
- Financial services industry (e.g., banks) or global development institutions (e.g., World Bank) limiting access to capital.

1.8.2 Big Message

- More natural gas is not an effective long-term strategy for the climate – it is less carbon intensive than coal, but its infrastructure has a long life so it competes with the adoption of lower-carbon alternatives as they scale up.

1.8.3 Key Dynamics

- If gas is taxed, in absence of other policies, primary energy demand for natural gas decreases, but high-carbon coal and oil demand increases slightly. We call this the “squeeze the balloon” problem – depressing fossil fuel emissions in one area causes them to pop up in another. Adding a carbon price is a good solution to the “squeeze the balloon” problem, as it addresses all fossil fuels together.
1.8.4 Potential Co-Benefits of Discouraging Natural Gas

- Gas drilling is water intensive, so limiting extraction can improve water security and quality at the source of production and protect wildlife habitats, biodiversity, and ecosystem services.\(^{12}\)
- There are concerns about the health and environmental impacts of the gas drilling approach, known as fracking, that have led many places to ban it.\(^{145}\)

1.8.5 Equity Considerations

- Generally speaking, natural gas production in developed countries is disproportionately located near low-income and minority communities.\(^{67}\)
- There have been cases where wealthy white communities have successfully resisted natural gas development and it has shifted to low-income communities predominantly inhabited by people of color. Low income communities often have less ability to influence development.\(^{89}\)
- Limited data on the placements of fracking and power plant sites in developing countries exists, yet macro-level research shows that low-income communities and communities of color disproportionately experience the negative impacts of natural gas drilling and burning.\(^{10}\)

1.8.6 Slider Settings

The following table highlights the numerical ranges for the labelled input levels of the Natural Gas slider. Each of the energy supply sliders is set to reflect a similar percentage cost increase or decrease for each input level.

<table>
<thead>
<tr>
<th>Change in price per thousand cubic feet (Mcf)</th>
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<th>highly taxed</th>
<th>taxed</th>
<th>status quo</th>
<th>subsidized</th>
</tr>
</thead>
<tbody>
<tr>
<td>+$5.00 to +$2.00</td>
<td>+$2.00 to +$1.00</td>
<td>+$1.00 to +$0.30</td>
<td>+$0.30 to -$0.30</td>
<td>-$0.30 to -$1.00</td>
<td></td>
</tr>
<tr>
<td>Cost increase or decrease</td>
<td>+200% to +60%</td>
<td>+60% to +30%</td>
<td>+30% to +10%</td>
<td>+10% to -10%</td>
<td>-10% to -30%</td>
</tr>
</tbody>
</table>

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1.8. Natural Gas
1.8.7 Model Structure

The cost of natural gas affects three significant decisions regarding energy infrastructure:

1. Investment in new capacity (whether or not to build new processing and power plants);
2. use of capacity (whether to run existing plants);
3. retirement of capacity (whether to keep plants longer or shorter than the average of ~30 years).

1.8.8 FAQs

**How can I directly force deeper reductions in natural gas use?** Consider selecting the “Stop building new natural gas infrastructure” switch in the advanced view, and changing the “% Reduction in gas utilization” slider.

Please visit support.climateinteractive.org for additional inquires and support.

1.9 Bioenergy

**Discourage or encourage the use of trees, forest waste, and agricultural crops to create energy.** Bioenergy is energy produced from the burning, or combustion, of living organic material such as wood, algae, or agricultural crops. There are a variety of bioenergy sources, some of which can be sustainable and others which can be worse than burning coal.

1.9.1 Examples

- Government incentives and/or targets to convert land into growing biofuel feedstocks and drive bioenergy development.
- Research, development, and investment into new technologies that can produce new forms of biofuels, and vehicles and industry that can use or support these biofuels.

1.9.2 Big Message

- Bioenergy is not a high leverage response to climate change – while it uses a renewable resource, it still emits large amounts of carbon dioxide and faces supply constraints with scale up.

1.9.3 Key Dynamics

- As bioenergy is subsidized or taxed, notice that the temperature changes very little. Changes in bioenergy shift the amount of other energy sources, which can mean things like more coal if bioenergy is taxed or less renewables if bioenergy is subsidized.
- Bioenergy is only zero-carbon if the feedstock is regrown to account for the carbon emitted. In some areas, trees are being used for bioenergy, which will take decades to regrow to make up for the carbon released when burned.
1.9.4 Potential Co-Benefits of Discouraging Bioenergy

- Crops and arable land are freed for other uses, such as food production when bioenergy is discouraged.
- Leaving sources of biomass, like forests, intact enables biodiversity to be preserved.
- A reduction in biomass burning can improve indoor and outdoor air quality from reduced soot and particulates.
- Bioenergy can accelerate deforestation through dependence on wood for fuels or through the expansion of bioenergy crops, particularly in the tropics. Less deforestation has many benefits including additional carbon sequestration.

1.9.5 Equity Considerations

- Land used for bioenergy crops can reduce land availability for food production and compromise food security.
- Farmer livelihoods can be severely impacted by shifting agriculture markets, so steps should be taken to help workers and farmers transition to shifting crop demands.

1.9.6 Slider Settings

The following table highlights the numerical ranges for the labelled input levels of the Bioenergy slider. Each of the energy supply sliders is set to reflect a similar percentage cost increase or decrease for each input level.

<table>
<thead>
<tr>
<th>Change in price per barrel of oil equivalent (boe)</th>
<th>highly taxed</th>
<th>taxed</th>
<th>status quo</th>
<th>subsidized</th>
<th>highly subsidized</th>
</tr>
</thead>
<tbody>
<tr>
<td>+$30 to +$15</td>
<td>+$15 to +$5</td>
<td>+$5 to -$5</td>
<td>-$5 to -$15</td>
<td>-$15 to -$30</td>
<td></td>
</tr>
</tbody>
</table>

| Cost increase or decrease | +60% to +30% | +30% to +10% | +10% to -10% | -10% to -30% | -30% to -60% |

1.9.7 Model Structure

- This sector tracks several stages of bioenergy installations, or energy supply capacity including: capacity under development, under construction, and actually producing energy, as well as the delays between each stage.
- Future modeling in this sector will add more refinement to the ways the bioenergy supply is characterized and include stronger links to the amount of available land.

Please visit support.climateinteractive.org for additional inquiries and support.

1.10 Renewables

Encourage or discourage building solar panels, geothermal systems, and wind turbines. Renewable energy includes wind, solar, geothermal, hydropower, and other technologies that produce energy with little to no carbon dioxide emissions. Note that nuclear and bioenergy are considered separately.
1.10.1 Examples

- Governments offering tax incentives to families installing solar panels on their roofs.
- Farmers and land owners allowing the installment of wind turbines on their land.
- Research and development for improvements to renewable energy technologies in order to improve efficiencies and/or reduce costs.
- Businesses committing to powering themselves with 100% renewable energy.

1.10.2 Big Message

- Subsidizing renewable energy helps to limit coal and gas demand and reduce future temperature. Without other actions, however, it isn’t enough to keep fossil fuels in the ground.

1.10.3 Key Dynamics

- Impact. As you encourage renewables, watch demand for Renewables (in green) grow and the demand for Coal (in brown) and Natural Gas (in blue) reduce in the “Global Sources of Primary Energy” graph. Renewable energy is already growing steadily in the Baseline scenario so the additional subsidies help reduce emissions but only so much.
- Price-demand feedback. Additionally, subsidies to renewables decrease energy costs, which increase energy demand over what it would have been otherwise (people use more energy when it is cheap). This feedback effect somewhat reduces the positive impact of encouraging renewable energy. View this dynamic with the graph “Final Energy Consumption.”
- Delays. It takes time for the subsidies and encouragement of renewables to show up in installed capacity. Subsidies are phased in over 10 years so note in the “Renewable Final Energy Consumption” graph that the Current Scenario does not immediately differ from the Baseline.

1.10.4 Potential Co-Benefits of Encouraging Renewables

- Decreased air and water pollution from switching away from fossil fuel sources can improve public health, worker productivity, and savings for governments and households.
- Renewables can help expand energy access during power outages.
- Renewable energy offers opportunities for high- and low-skilled employment.

1.10.5 Equity Considerations

- Although the price of renewable energy infrastructure continues to fall, many low-income communities remain unable to access the technology in both developed and developing countries. Working to ensure an equitable energy transition can help everyone to reap the benefits.¹
- Policies in many developed countries limit solar and wind subsidy programs to homeowners, who often occupy higher income brackets.

1.10.6 Slider Settings

The following table highlights the numerical ranges for the labelled input levels of the Renewables slider. Each of the energy supply sliders is set to reflect a similar percentage cost increase or decrease for each input level.

<table>
<thead>
<tr>
<th>Change in price per kilowatt hour (kWh)</th>
<th>taxed</th>
<th>status quo</th>
<th>subsidized</th>
<th>highly subsidized</th>
</tr>
</thead>
<tbody>
<tr>
<td>+$0.02 to +$0.01</td>
<td>+$0.01 to</td>
<td>-$0.01 to</td>
<td>-$0.02 to</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-$0.01</td>
<td>-$0.02</td>
<td>-$0.03</td>
<td></td>
</tr>
<tr>
<td>Cost increase or decrease</td>
<td>+30% to +10%</td>
<td>+10% to -10%</td>
<td>-10% to -30%</td>
<td>-30% to -60%</td>
</tr>
</tbody>
</table>

1.10.7 Model Structure

This sector tracks the time it takes wind and solar installations to move through several stages – capacity under development, under construction, and actually producing energy.

The most important feedback loops in the renewables sector include:

1. Overheating – costs go up when demand grows faster than the manufacturing and support industries can keep up.
2. Site availability – efficiency goes down and costs go up when renewables are sited in less optimal locations (e.g., solar power in rainy climates).
3. Learning effect – every doubling of cumulative production will bring costs down 20% (aka, the progress ratio). Costs come down as supply chains, business models, and production industries grow.

1.10.8 Case Studies

United States: Scaling up wind and solar energy sources is estimated to have avoided 7,000 premature deaths and saved $87.6 B in health costs and climate impacts from 2007-2015.²

Benin: Solar-powered drip irrigation for women farmers was shown to increase household vegetable production and consumption, increase income level, and decrease food insecurity.³

Global: Increasing the share of renewable energy in the global energy supply to 65% could generate 6 million jobs and add $19 trillion to the world economy by 2050.⁴

1.10.9 FAQs

Why doesn’t encouraging renewables with a big subsidy avoid much future warming alone?

- Renewables only reduce CO₂ emissions when they displace fossil fuels. In some cases renewable energy just meets new energy demand and doesn’t replace the demand met by coal and gas.
- Second, there is a price-demand feedback effect – in order to grow, renewables are made less expensive. The drop in energy price boosts demand, undoing some of the positive effect.

How can I get renewables to grow faster?

---


• Discourage coal and oil by taxing them individually or setting a carbon price.

• Adjust the “Renewables R&D breakthrough cost reduction” slider to simulate a sudden breakthrough that would dramatically lower the cost of renewable energy.

**How do you handle the availability and cost of storage of electricity from renewables?**

• The cost of storage for renewables is explicitly modeled in En-ROADS, and as renewables become a significant part of energy supply, storage must be cost effective to enable further expansion.

Please visit support.climateinteractive.org for additional queries and support.

### 1.11 Nuclear

**Encourage or discourage building nuclear power plants.** Nuclear power production does not release carbon dioxide, but it produces harmful nuclear waste.

#### 1.11.1 Examples

**Discouraging**

• Public information campaigns to raise public concerns about the risks of nuclear power.

• Policies to retire existing nuclear power plants.

**Encouraging**

• Government policies aimed at handling nuclear waste and reducing costs of nuclear power.

• Corporate efforts to promote public acceptance of nuclear power plants.

#### 1.11.2 Big Message

• Nuclear is not a huge driver of future temperature and competes with the growth of renewables and new zero-carbon technology.

• It could be part of a suite of climate action if one is willing to accept the environmental costs – e.g., handling waste materials and the risk of radiation damage near the plants.

#### 1.11.3 Key Dynamics

• As you subsidize nuclear, watch Nuclear (light blue area) grow, and Coal (brown area) and Natural Gas (dark blue area) decrease in the “Global Sources of Primary Energy” graph. Nuclear displaces some fossil fuel sources, which keeps more carbon in the ground and helps reduce temperature modestly.

• Nuclear competes with all energy sources available, so notice also what happens to Renewables (green area) when nuclear is incentivized —it decreases too.
1.11.4 Potential Co-Benefits of Discouraging Nuclear

- Risk of exposure to radiation from a nuclear meltdown or hazardous waste is reduced.
- Nuclear energy can use more water than coal for electricity production, so discouraging nuclear power can increase water security and help protect wildlife habitats, biodiversity, and ecosystem services.1
- Nuclear energy is fueled by uranium which can be harmful to mine, so discouraging nuclear energy can reduce risks to miners.

1.11.5 Equity Considerations

- Nuclear power plants, uranium mines (which provide the fuel for nuclear power), and waste sites are often located in low-income, marginalized communities that often lack resources to advocate for stricter environmental regulations and oversight.2
- Mining uranium poses significant health risks to miners as well as surrounding communities due to water contamination and toxic waste.

1.11.6 Slider Settings

The following table highlights the numerical ranges for the labelled input levels of the Nuclear slider. Each of the energy supply sliders is set to reflect a similar percentage cost increase or decrease for each input level.

<table>
<thead>
<tr>
<th>Change in price per kilowatt hour (kWh)</th>
<th>highly taxed</th>
<th>taxed</th>
<th>status quo</th>
<th>subsidized</th>
<th>highly subsidized</th>
</tr>
</thead>
<tbody>
<tr>
<td>+$0.07 to +$0.03</td>
<td>+$0.03 to +$0.01</td>
<td>+$0.01 to -$0.01</td>
<td>-$0.01 to -$0.03</td>
<td>-$0.03 to -$0.07</td>
<td></td>
</tr>
<tr>
<td>Cost increase or decrease</td>
<td>+60% to +30%</td>
<td>+30% to +10%</td>
<td>+10% to +10%</td>
<td>-10% to -30%</td>
<td>-30% to -60%</td>
</tr>
</tbody>
</table>

1.11.7 Model Structure

This sector tracks several stages of nuclear power plants, or energy supply capacity: capacity under development, under construction, and actually producing energy, including delays between each stage.

Please visit support.climateinteractive.org for additional inquiries and support.

1.12 New Zero-Carbon

Discover a brand-new cheap source of electricity that does not emit greenhouse gases. Some speculate that such a breakthrough could be nuclear fusion or thorium-based nuclear fission. Decide when the breakthrough occurs, its initial cost relative to coal, and how long the delays in commercialization and scale up would be.

1.12.1 Examples

- Research and development, or other investment into new sources of energy supply such as thorium fission or nuclear fusion.
- Note, this does not include new technologies in CO$_2$ removal, transportation, electrification, or energy efficiency.

1.12.2 Big Message

- The potential contribution of a new energy supply technology is severely hampered by the long amount of time it takes new technologies to scale up. Even under optimal conditions, it would take decades to displace fossil fuels, and actually reduce greenhouse gas emissions.

1.12.3 Key Dynamics

- Watch the orange area of New Zero-Carbon go up as a breakthrough in a new zero-carbon energy supply occurs in the “Global Sources of Primary Energy” graph. Notice that temperature drops only modestly. There are two reasons why:
  - First, notice it takes a long time for the new technology to grow and become a large part of the global energy mix. There is a long delay between discovery of the zero-carbon energy technology and its dominance in the market – 10 years to commercialize, several years to plan and build, and then growing only as existing coal and natural gas plants (which have a lifetime of 30 years) are retired. Watch how little Coal (brown area) and Natural Gas (dark blue area) go down before 2040. Because of this, very little carbon is kept underground during this critical period.
  - Second, look at the “Final Energy Consumption” graph. The reason the new zero-carbon technology grows quickly is that it is cheaper than all other energy supplies, so the abundance of inexpensive energy increases demand to higher than it would be otherwise.

1.12.4 Potential Co-Benefits of a Breakthrough in New Zero-Carbon

- A breakthrough in a new energy sources would create jobs along the supply chain from research and development to construction to operations.
- Research advancements in new technologies may be useful for other applications.

1.12.5 Equity Considerations

- There are unknown consequences and risks associated with new energy sources, and oftentimes these technologies can end up being located in vulnerable communities.

1.12.6 Slider Settings

<table>
<thead>
<tr>
<th></th>
<th>status quo</th>
<th>breakthrough</th>
<th>huge breakthrough</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breakthrough year</td>
<td>no breakthrough</td>
<td>2022</td>
<td>2022</td>
</tr>
<tr>
<td>Time to commercialize</td>
<td>10 years</td>
<td>10 years</td>
<td></td>
</tr>
<tr>
<td>Initial cost relative to coal</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
1.12.7 Model Structure

The path to deployment will take some time after the success of the technology in the laboratory: commercialization (set at 10 years, roughly the same amount of time that Uranium-based fission took), planning (2 years), and construction (5 years). Then the new energy source must compete with other energy sources.

Please visit support.climateinteractive.org for additional inquiries and support.

1.13 Carbon Pricing and Energy Standards

Set a global carbon price that makes energy sources more expensive depending on how much carbon dioxide they release, or enact a clean electricity standard or emissions performance standard. Energy producers frequently pass additional costs to their customers, so policy must be designed to minimize the impacts on the poorest.

1.13.1 Examples

- Countries and regions implementing carbon taxes.
- Grassroots campaigns generating public support for carbon pricing.
- Clean Electricity Standards are similar to Renewable Portfolio Standards in use in several US States or the Renewables Obligation in the UK.

1.13.2 Big Message

- Pricing carbon is a high leverage strategy, as it both reduces the carbon intensity of the energy supply and reduces the overall energy demand.
- Clean Electricity Standards only affect part of the energy system, and so their leverage depends on being used in conjunction with electrification of transport and buildings and industry.

1.13.3 Key Dynamics

- When the carbon price is increased, notice that Coal (brown area) reduces the most in the “Global Sources of Primary Energy” graph. It is the most carbon intensive source of energy, which makes it the most sensitive to a carbon price. Natural Gas (dark blue area) decreases as well, although more modestly. Oil (red area) decreases only slightly, even though it is more carbon intensive than gas, because it is not easily substituted for other energy sources (e.g. can’t power a diesel truck with wind power). Renewables (green area) increases as the relative cost of wind and solar make them more attractive.
- Just like taxing coal, a significant carbon price increases energy costs, which reduces energy demand. View this in the “Final Energy Consumption” graph, noting that the high carbon price Current Scenario (blue line) is lower than Baseline (black line).
- The economic effects of these policies are best seen as the cost of energy plus the cost of subsidies minus the revenue from taxes. See the two graphs “Total Annual Cost of Energy” and “Revenue & Cost from Taxes & Subsidies.”
1.13.4 Potential Co-Benefits of a Carbon Price

- Renewable energy becomes relatively cheaper, which can incentivize job creation in the sector.
- Reducing the use of fossil fuels improves air quality, increasing healthcare savings and worker productivity.
- Revenue from carbon pricing can be allocated to social programs that can be shared with everyone.

1.13.5 Equity Considerations

- As carbon taxes reach effective levels, companies may try to pass costs to customers, where the poor are most at risk of being impacted. Policies can be developed that limit this impact.
- Workers employed in fossil fuel industries risk losing their jobs if companies shrink workforces in response to higher costs of production, so job transition plans should be in place and protections for workers ensured.
- Due to the political nature of fossil fuel production, government corruption and rent-seeking could create the possibility of certain industries avoiding the carbon price due to loop holes or exemptions.

1.13.6 Slider Settings

<table>
<thead>
<tr>
<th>status quo</th>
<th>low</th>
<th>medium</th>
<th>high</th>
<th>very high</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon price per ton</td>
<td>no carbon price</td>
<td>$0 to $20</td>
<td>$20 to $60</td>
<td>$60 to $100</td>
</tr>
</tbody>
</table>

Clean Electricity Standard

The switch “Use clean electricity standard” sets a policy which requires a certain percentage of electricity to come from qualifying sources. This creates a system of incentives: producers of qualifying electricity receive additional revenue, like a subsidy except that the money comes through electricity prices rather than government spending. The added costs and revenues affect electricity markets and investment, pushing the mix of generation toward the target standards. The value of the incentive depends on the gap between target and actual generation, and on how ambitious the target is.

Under “Sources that qualify as clean electricity,” check the boxes for which sources qualify as “clean.” You can see the percent these sources contribute on the graph “% Electricity Consumption from Qualifying Sources.” Use the “Target % electricity from qualifying sources” slider to set the required amount of qualifying electricity.

1.13.7 Case Studies

Northeast United States: A 2016 MIT study examined a scenario where the Northeast United States implemented a carbon cap and trade program and found that the annual health savings to the region could be five times greater than the costs of the changes needed to satisfy the policy.¹

Please visit support.climateinteractive.org for additional inquires and support.

1.14 Transport – Energy Efficiency

Increase or decrease the energy efficiency of vehicles, shipping, air travel, and transportation systems. Energy efficiency includes things like hybrid cars, expanded public transport, and ways that people can get around using less energy. Adopting more energy efficient practices, such as cycling and walking, can improve public health and save money.

1.14.1 Examples

- Individuals changing their personal behavior to increase walking, biking, using public transit, carpooling, living in higher density neighborhoods, purchasing more efficient vehicles, reducing flying, or telecommuting.
- Public or corporate policies such as increasing parking prices, investing in public transit, offering tax breaks for efficient vehicles, rewarding carpooling, building bike lanes, creating high density pedestrian friendly urban areas, or performance standards that mandate specific fuel efficiency.
- Research and development into high efficiency technologies for shipping, vehicles, and air travel.

1.14.2 Key Dynamics

- Watch Oil (red area) decrease in the “Global Sources of Primary Energy” graph as the world increases the efficiency of its transport. Less oil is burned, and coal and gas fall as well as electrified transport becomes more efficient.
- View the “Final Energy Consumption” graph to see the fall in energy demand.
- To see another benefit, look at the “Cost of Energy” graph. Less demand for energy means prices are lower.

1.14.3 Potential Co-Benefits of Encouraging Energy Efficiency

- Improved air quality as a result of less burning of fossil fuels increases healthcare savings and worker productivity.
- Better fuel efficiency means energy costs are lower.
- Mass transit, like buses and trains, can reduce traffic congestion and noise.
- Improved biking and walking infrastructure increases physical activity and safety, which results in sizeable health savings.

1.14.4 Equity Considerations

- In some developed countries, such as the United States, pedestrian and cycle-friendly infrastructure has been concentrated in wealthy communities, leaving out low-income families and people of color.¹
- When mass transit options improve or operating costs decrease with fuel efficient vehicle use, social equality may improve, as low-income individuals have more transportation options to meet their needs.

1.14.5 Slider Settings

The variable being changed is the annual improvement rate in the energy intensity of new transport capital such as vehicles, trains, and ships.

<table>
<thead>
<tr>
<th>Annual rate</th>
<th>Discouraged</th>
<th>Status quo</th>
<th>Increased</th>
<th>Highly Increased</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1% to 0%</td>
<td>0% to +1%</td>
<td>+1% to +3%</td>
<td>+3% to +5%</td>
<td></td>
</tr>
</tbody>
</table>

1.14.6 Model Structure

Increasing the improvement rate in energy use for new vehicles and other infrastructure helps drive reductions in greenhouse gas emissions across the transport sector. There is some delay in how fast this accelerates because energy use is driven by the overall average of all capital (not just the new things). The model structure tracks overall efficiency, which includes retrofitting of existing capital.

1.14.7 Case Studies

New York City: A program that supports students walking and biking to school spent $10 million and saved $230 million from increased physical activity, reduced air pollution, and decreased injury rates.2

Barcelona, Spain: Replacing 20% of Barcelona’s car trips with bikes could save 38 lives per year from decreased air pollution and increased physical activity, while also reducing 21,000 tons of CO2 per year.3

Please visit support.climateinteractive.org for additional inquiries and support.

1.15 Transport – Electrification

Increase purchases of new electric cars, trucks, buses, trains, and possibly even ships and airplanes. Using electric motors for transport helps reduce greenhouse gas emissions and air pollution if the electricity is from low-carbon sources like solar and wind.

1.15.1 Examples

- Investments into electric vehicle charging infrastructure.
- Research and development into the technologies for vehicles, batteries, and charging.
- Corporate commitments to sales of electric vehicles.
- Programs to offer rebates and incentives to electric car purchases.

---


1.15.2 Big Message

- If the world is dependent on coal and natural gas for electric power, the net effect of electrification is only a slight change in emissions and temperature.
- Switching to electric modes of transport makes the biggest impact for the climate when electrical energy sources are low-carbon.

1.15.3 Key Dynamics

- As you increase Transport Electrification, there are two main forces that affect future temperature:
  - Overall efficiency is greater for electrified transport than for internal combustion engines – in general, less fuel is used to power transport with electricity than oil.
  - Oil, in the “Global Sources of Primary Energy” graph, goes down as we electrify transport. At the same time, primary energy demand for coal, renewables, and to a more limited extent, natural gas, all increase to power the rise in electrical demand.

1.15.4 Potential Co-Benefits of Encouraging Electrification

- Improved air quality from fewer internal combustion engines increases healthcare savings and worker productivity.
- Jobs are created in the manufacturing and sales of electric batteries and engines.

1.15.5 Equity Considerations

- Although costs are coming down, electric vehicles may not be affordable or available to everyone.
- Mining of lithium and copper, two necessary ingredients for the batteries used in electric vehicles, can be damaging to precious ecosystems and threaten the well-being of communities near mining sites.¹
- Electric charging station locations may not be accessible or the electric battery range may be insufficient for some situations.

1.15.6 Slider Settings

The main Transport Electrification slider adds a policy mandating the minimum percentage of new road and rail transport (cars, trucks, buses, and trains) that must be powered by electricity rather than fuels.

Note that other actions can contribute to electrification and can result in higher levels of electrification than what the slider target is set to.

With the “Electrification of new transport – air and water” slider in the advanced settings you can set the percentage of new electric airplanes, ships, boats, etc. that use air or water to get around. Currently, electric airplanes and long-range electric ships are only available as prototypes and face significant technological challenges due to the limitations of energy storage, so the default assumption is that they do not scale up. If the slider is moved, then the percentage of electrification action would begin in 2030 and take 70 years to reach the specified percentage.

1.15.7 Model Structure

This input directly forces growth of electrification up to a minimum percentage, unlike the inputs for energy sources, which change the financial attractiveness to drive future behavior.

This input affects climate outcomes through two pathways:

1. Changing energy demand. The efficiency for electrified energy use is greater than for the direct burning of coal, oil, and gas.

2. Changing fuel mix. Increased electrification decreases use of oil but then increases use of coal, natural gas, and renewables in electricity generation.

1.15.8 Case Studies

United States: Increasing fuel economy standards in the United States could save consumers tens of billions of dollars per year, reduce gas consumption by tens of billions of gallons per year, and create over 300,000 jobs by 2030 while also reducing greenhouse gas emissions by millions of tons per year.

Please visit support.climateinteractive.org for additional inquiries and support.

1.16 Buildings and Industry - Energy Efficiency

Increase or decrease the energy efficiency of buildings, appliances, and other machines. Energy efficiency includes things like building well-insulated homes and reducing the amount of energy factories use. Energy efficient practices can save money through reduced energy needs as well as improve the health of people in those buildings.

1.16.1 Examples

- Individuals and businesses insulating buildings, purchasing energy efficient technologies (motors, lighting, appliances, servers, HVAC systems), and conserving energy.

- Government policies such as tax breaks and performance standards to incentivize energy efficient products and practices.

- Research and development into high efficiency technologies.

---

1.16.2 Big Message

- Energy efficiency of buildings and industry is high leverage. It leads to less overall energy use, which leads to less coal, oil, and gas being used. It also saves families, business, and communities money.

1.16.3 Key Dynamics

- As less energy is used for buildings and industry, notice how all the energy sources decline in the “Global Sources of Primary Energy” graph - particularly coal and gas when they are the main sources of electricity. Less fossil fuels are burned so CO\textsubscript{2} emissions go down and global temperature change is lowered dramatically.
- Improvements in energy intensity of new capital also reduce energy demand. Explore this in the “Final Energy Consumption” graph, where the Current Scenario (blue line) is lower than the Baseline (black line).

1.16.4 Potential Co-Benefits of Encouraging Energy Efficiency

- Increased industrial efficiency and reduced energy demand can reduce air pollution, which increases healthcare savings and worker productivity.
- Lowering electricity bills for households, businesses, and governments increases energy security.
- Insulated homes remain cooler in the summer and warmer in the winter, when weather events and grid-overload cause outages.
- Retrofitting buildings and homes to be more efficient can create many jobs.

1.16.5 Equity Considerations

- The up-front capital costs of efficiency improvements may not be accessible to lower income individuals and small businesses.
- In some places, policies are directed at property owners, inhibiting renters, who are often lower income, from accessing the benefits.

1.16.6 Slider Settings

The variable being changed is the annual improvement rate in the energy intensity of new capital for buildings and industry.

<table>
<thead>
<tr>
<th>Annual rate</th>
<th>discouraged</th>
<th>status quo</th>
<th>increased</th>
<th>highly increased</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1% to 0%</td>
<td>0% to +1.5%</td>
<td>+1.5% to +3%</td>
<td>+3% to +5%</td>
<td></td>
</tr>
</tbody>
</table>
1.16.7 Model Structure

Increasing the rate of improvement in energy use for buildings and industry lowers emissions gradually, because energy use is driven by the overall average of all infrastructure in this area, which is delayed from this intervention because improvement only come to new things and many buildings and industrial facilities last decades.

1.16.8 Case Studies

Global: Through LEED-certified energy efficient buildings, a group of six major economies saved $13.3 billion in energy, health, and climate benefits and avoided emitting dozens of air pollutants.¹

United Kingdom: If the UK were to reduce its household energy expenditures by one-quarter using energy efficiency measures, households could save £270 per year. The net present value of this investment is £7.5 billion, and the wider health, economic, and energy benefits could reach £47 billion.²

Please visit support.climateinteractive.org for additional inquiries and support.

1.17 Buildings and Industry - Electrification

Increase the use of electricity, instead of fuels like oil or gas, in buildings, appliances, heating systems, and other machines. Using electric motors only helps reduce emissions if the electricity is from low-carbon sources like solar and wind.

1.17.1 Examples

- Increase in public interest for replacing oil and gas heating furnaces in buildings with electric heating systems.
- Research and development into various electric motors and systems that could enable wind and solar to replace oil and gas fired industrial facilities.

1.17.2 Big Message

- Electrification of buildings and industry can help, particularly when renewable energy is already encouraged or fossil fuels are discouraged.

1.17.3 Key Dynamics

- When there are more efficient electrical systems powering buildings and industries, notice that Natural Gas (dark blue area) and Coal (brown area) move down in the “Global Sources of Primary Energy” graph.

1.17.4 Potential Co-Benefits of Encouraging Electrification

- Improved air quality at the source increases healthcare savings and worker productivity.
- Eliminating demand for natural gas lines to buildings also eliminates the risks from fire and explosion.
- Noise pollution from motor engines, generators, and furnaces is reduced.
- Air quality for individuals working/living in and around the structures is improved, which increases healthcare savings and worker productivity.

1.17.5 Equity Considerations

- The up-front capital costs of retrofitting buildings and heating systems to be entirely electric may not be accessible to lower-income individuals and small businesses.
- Exposure to household air pollution is unevenly distributed within and across countries, to which negative health effects and poverty are strongly correlated.¹

1.17.6 Slider Settings

The Buildings & Industry Electrification slider adds a policy mandating the minimum percentage of new building construction, industry, and appliances that must be powered by electricity rather than fuels.

Note that other actions can contribute to electrification and can result in higher levels of electrification than what the slider target is set to.

<table>
<thead>
<tr>
<th>status quo</th>
<th>incentivized</th>
<th>highly incentivized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum percentage of new buildings and industry</td>
<td>0% to 39%</td>
<td>40% to 69%</td>
</tr>
</tbody>
</table>

1.17.7 Model Structure

This input directly forces growth of electrification up to a minimum percentage, unlike the inputs for energy sources, which change the financial attractiveness to drive future behavior.

This input affects climate outcomes through two pathways:

1. Changing energy demand. The efficiency for electrified energy use is greater than for the direct burning of coal, oil, and gas.

2. Changing fuel mix. Increased electrification decreases use of oil but then increases use of coal, natural gas, and renewables in electricity generation.

Please visit support.climateinteractive.org for additional inquiries and support.

1.18 Population Growth

Assume higher or lower population growth. Population is a key driver of increased greenhouse gases; however, this is also tied heavily to consumption habits. Women’s education and access to family planning could accelerate shifts to smaller families worldwide.

1.18.1 Examples

- Different assumptions for future fertility rates and demographics.
- Greater empowerment of women and girls, resulting in lower fertility rates.
- Increased education on and access to reproductive health services.

1.18.2 Big Message

- Contrary to some people’s beliefs, population growth is not a silver bullet for addressing climate change.
- Decisions around population and family choice are very personal decisions and efforts to shift these decisions have ethical implications in many cultures.

1.18.3 Key Dynamics

- Watch all the sources of energy change as you change population growth.

1.18.4 Potential Co-Benefits of Lower Growth

- Lower population growth reduces global consumption of resources.
- Ensuring safe access to family planning, reproductive health services, and women’s education enhances quality of life and income for women.

1.18.5 Equity Considerations

- Policies around population should be voluntary and empower women to make the choices that are best for them.
- A higher percentage of women of color live in countries with severe gender inequities in access to education, full economic and political participation, and adequate family planning. Reducing population growth necessitates a large investment in that particular group.
- There is a history of women of color in both high- and low-income countries being forcibly sterilized to prevent giving birth; this should never be encouraged.\textsuperscript{1,2,3,4}

### 1.18.6 Slider Settings

The slider reflects the 95% probability range of population deviating from the United Nation’s medium population growth path. The variable being changed reflects the global population by 2100, in billions of people.

<table>
<thead>
<tr>
<th>UN Scenario</th>
<th>lowest growth</th>
<th>low growth</th>
<th>status quo</th>
<th>high growth</th>
<th>highest growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population in 2100</td>
<td>9.1 to 9.5 billion</td>
<td>9.5 to 10.5 billion</td>
<td><strong>10.5 to 11.4 billion</strong></td>
<td>11.4 to 12.8 billion</td>
<td>12.8 to 13.2 billion</td>
</tr>
</tbody>
</table>

### 1.18.7 Model Structure

Population gets multiplied with economic growth (GDP per capita) to equal total global GDP, or Gross World Product. Please visit support.climateinteractive.org for additional inquires and support.

### 1.19 Economic Growth

**Assume higher or lower growth in goods produced and services provided.** Economic Growth is measured in Gross Domestic Product (GDP) per person and is a key driver in energy consumption. Alternatives exist to meeting people’s needs through economic frameworks not based on constant GDP growth.

#### 1.19.1 Examples

- Global efforts to reduce overconsumption and embrace voluntary simplicity.
- Possible impacts on economic growth from the effects of climate change.

#### 1.19.2 Big Message

- Slower economic growth would be a high leverage approach for avoiding future temperature increases, however, there are lots of questions about how this might occur and be done in a way that is equitable.

#### 1.19.3 Key Dynamics

- Population gets multiplied with GDP per capita to equal total global GDP, or Gross World Product. Increases in this variable accelerate the exponential growth of GDP, arguably the most important driver of future carbon dioxide emissions.
- Watch all the sources of energy change as you change economic growth.
- As you increase the economic damage caused by climate change, notice how this reduces the emissions, but cannot halt the temperature increase even under extreme assumptions where the world’s GDP plummets.
1.19.4 Potential Co-Benefits of Lower Growth

- Focus may be shifted to alternative measures of prosperity that enhance people’s wellbeing, such as gross national happiness.
- Greater focus on resource conservation and less on material consumption can lead to less waste.

1.19.5 Equity Considerations

- Economic growth is tied to pulling people out of poverty worldwide. Although, in recent decades, many gains in economic growth have gone to the world’s wealthiest. Regardless, policies must be tailored to specific local and regional circumstances.
- When GDP growth slows or contracts, governments can incur higher budget deficits, often implementing austerity measures—cutting spending and raising taxes—to offset the difference. These reforms can severely impact the poor and working class causing job losses and all the inequities that come with loss of livelihood.¹

1.19.6 Slider Settings

**Economic Growth**

<table>
<thead>
<tr>
<th></th>
<th>low growth</th>
<th>status quo</th>
<th>high growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-term economic growth</td>
<td>0.5% to 1.2%</td>
<td><strong>1.2% to 1.9%</strong></td>
<td>1.9% to 2.5%</td>
</tr>
<tr>
<td>Near-term economic growth</td>
<td>1.7% to 2.1%</td>
<td><strong>2.2% to 2.9%</strong></td>
<td>3.0% to 3.7%</td>
</tr>
</tbody>
</table>

The “Long-term economic growth” slider is the main slider that is used for controlling economic growth, however, more precise assumptions about economic growth can be set by also adjusting the “Near-term economic growth” slider. This slider sets the initial global average growth in GDP per person. The slider “Transition time” is available to change the amount of time it takes for the “Near-term economic growth” level to reach the “long-term economic growth” level.

**Reduction in GDP from Climate Impacts**

The two sliders “Reduction in GDP at 2°C from climate impacts” and “Maximum reduction in GDP” (located in the Assumptions menu under ‘Economic impact of climate change’) enable the user to explore the strength of the feedback between climate impacts and economic growth. These two sliders are displayed on a single line since they are related to each other. Maximum reduction in GDP cannot be smaller than Reduction in GDP at 2°C, hence they move together if a user tries to move them past each other. To see the dynamics as you adjust these sliders, view the graph “Reduction in GDP vs Temperature.”

Climate change is expected to have multiple adverse effects on the economy, such as decreased investment in goods and services due to the cost of responding to changes in extreme weather events, sea level rise, desertification, crop yield decreases, flooding, and resulting migration. Several economists formulated this impact, known as the “damage function,” as a percentage reduction on global GDP, and estimated it as a function of temperature change. The four main functions in the literature are from Nordhaus (2017), Weitzman (2012), Dietz & Stern (2015) and Burke et al. (2015). You can see their estimates for economic damage in the “Reduction in GDP vs Temperature” graph, and replicate them in En-ROADS by entering the following values for the two sliders, or by selecting the function in the ‘Preset’ menu:

1.19.7 Model Structure

In the real world, there would be multiple feedbacks to economic growth from energy prices, and various taxes, however, the model only features the feedback from climate impacts to GDP. The user can explore the other feedbacks by changing economic growth projections with the sliders manually.

Please visit support.climateinteractive.org for additional inquiries and support.

1.20 Methane & Other Gases

**Decrease or increase greenhouse gas emissions from methane, nitrous oxide, and the F-gases.** Methane is released from sources like cows, agriculture, natural gas drilling, and waste. Nitrous oxide comes from fertilizers. The f-gases, includes HFCs, PFCs, and others that are used in industry and consumer goods like air conditioners.

1.20.1 Examples

- Decreased meat consumption.
- Modified agricultural practices such as increasing digestion of manure and decreasing fertilizer use.
- Decreased methane leakage from oil and gas industries.
- Increased capturing of gases emitted from landfills.
- Research and development into substitutions for F-gases in industrial processes.

1.20.2 Big Message

- Reducing methane, nitrous oxide, and the F-gases is high leverage, although many approaches to reducing these emissions need more research and support to scale up.

1.20.3 Key Dynamics

- Methane, N$_2$O, and F-gas emissions comprise 30% of current greenhouse gas emissions and are key in reducing to address climate change.
1.20.4 Potential Co-Benefits of Decreasing Methane & Other Gases

- Plant-based diets have been shown to be healthier for individuals and have less impact on ecosystems.
- Sustainable and plant-based agriculture produces more food with fewer resources, which increases food security.
- Reducing methane leakage from natural gas systems can save money.
- Less nitrogen-rich fertilizer run off can reduce water pollution, decrease eutrophication, and increase marine health.

1.20.5 Equity Considerations

- Many cultural values are attached to certain foods, meaning change to more plant-based diets could require a large societal shift.
- Policies implemented without care may threaten food security for certain individuals and communities. For example, rice paddies, a large methane contributor, are a main dietary staple for many countries.
- Local economies and employment can be threatened in communities which currently rely on industrial, large-scale farming practices as their main livelihood.

1.20.6 Slider Settings

The variable being changed is the percent reduction or increase of total maximum action. The model limits how much these emissions can be reduced—so 100% max reduction is not a 100% total emissions reduction—since some are considered unavoidable, particularly those from agriculture, landfills, and wastewater.

<table>
<thead>
<tr>
<th>Percent reduction or increase of maximum action</th>
<th>highly reduced</th>
<th>moderately reduced</th>
<th>status quo</th>
<th>increased</th>
</tr>
</thead>
<tbody>
<tr>
<td>-100% to -50%</td>
<td></td>
<td>-50% to -2%</td>
<td>-2% to 0%</td>
<td>0% to +10%</td>
</tr>
</tbody>
</table>

1.20.7 Model Structure

Each greenhouse gas is modeled separately within En-ROADS, which enables the impact of each gas on global temperature to be handled without using global warming potential (GWP) and CO$_2$ equivalency conversions. Greenhouse gases other than CO$_2$ that are reflected in graphs with the units CO$_2$e do use GWP100 to enable comparison and reporting of all greenhouse gases together. This means that the short-lived, but high impact, nature of greenhouse gases like methane is captured.

1.20.8 Case Studies

Carrboro, NC, USA: Participation in a community gardening program in Carrboro, NC showed improvements in childhood obesity levels and resulted in families with children in the program eating one-third more fruits and vegetables every day.\(^1\)

Please visit support.climateinteractive.org for additional inquiries and support.

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1.21 **Deforestation**

**Decrease or increase the loss of forests for agricultural and wood product uses.** Deforestation often entails burning and removing forests to clear land for crops like soybeans, corn, or palm oil. Forest protection efforts increase biodiversity and can support community resilience.

### 1.21.1 Examples

- Government policy to preserve forested land and place restrictions on industries such as soybean and/or palm oil.
- Increased support for indigenous land rights.
- Public support and campaigns to support land preservation.

### 1.21.2 Big Messages

- Efforts to reduce deforestation are relatively low leverage for the climate, because the influence from energy CO$_2$ emissions is so dominant, but stopping deforestation is still part of a multi-pronged effort to address climate change.
- Protecting forests is helpful for many reasons other than climate action, including biodiversity conservation and protection of native peoples’ lands.

### 1.21.3 Key Dynamics

- Highly reducing deforestation emissions reduces temperature less than most people would estimate. View the “Greenhouse Gas Net Emissions by Gas – Area” graph to see the role of land use (deforestation) CO$_2$ relative to all the other sources of emissions.

### 1.21.4 Potential Co-Benefits of Decreasing Deforestation

- Forests protect biodiversity and provide ecosystem services and food sources.
- Forest preservation reduces erosion and prevents soil loss.
- Forests provide livelihoods for people (e.g., small-scale resource gathering and sustainable forestry) that can be lost when land is shifted to other uses.

### 1.21.5 Equity Considerations

- Forest preservation efforts have sometimes restricted the land access of indigenous people who have lived sustainably on the land for generations. Policies should be created with local stakeholder engagement.\(^1\)

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1.21.6 Slider Settings

| Percent per year reduction or increase | highly reduced ( -10% to -4%) | moderately reduced ( -4% to -1%) | status quo ( -1% to 0%) | increased ( 0% to +1%) |

1.21.7 Model Structure

Emissions from deforestation stay level in the Baseline scenario to reflect trends that indicate deforestation continues to be insufficiently addressed worldwide.

Please visit support.climateinteractive.org for additional inquiries and support.

1.22 Afforestation

Plant new forests and restore old forests. As trees grow, they draw carbon out of the air, which reduces the concentration of carbon dioxide. However, without care, large-scale afforestation can compromise biodiversity and historical land rights.

1.22.1 Examples

- Government policies, incentives, and funding to identify available land, plant trees, and manage forests.
- Business, land owner, and public support for large scale tree planting.

1.22.2 Big Message

- Afforestation has the potential to pull significant amounts of carbon dioxide out of the atmosphere, but land availability and other effects should be considered. It would take an immense amount of land to make a large impact on temperature change.

1.22.3 Key Dynamics

- Growing more trees boosts global removal of CO₂ from the atmosphere, as photosynthesis pulls carbon into biomass and soils. Watch the temperature decrease modestly as a result.
- Explore the graph “Land for Carbon Dioxide Removal.” The land area of India is 300 million hectares, so if we were to forest an area of that size we would still not see much change in temperature.
1.22.4 Potential Co-Benefits of Increasing Afforestation

- New forests can create new ecosystems and protect existing wildlife habitats, biodiversity, and ecosystem services.
- Larger and healthier tree canopies in cities reduce urban heat island effects and energy needed for heating and cooling.
- Jobs are created in tree planting, care, and maintenance.

1.22.5 Equity Considerations

- Afforestation entails shifting large areas of land into forests. This can sometimes result in monocultures of trees that are all the same age, which does not contribute to healthy biodiversity as much as natural forests.
- Large shifts in land can compromise historic land access, so involving low-income and minority communities, including Indigenous peoples, in the process of policy development and implementation is essential.

1.22.6 Slider Settings

The Afforestation slider changes the percentage of available land that is used to grow new forests. 100% would mean that 700 Mha of land are covered in forests. 700 Mha represents approximately 25% of current grassland area, nearly 10% of all land that is not currently forest, and just over the difference in forest area back in 1850 until now (i.e., there is 630 Mha less forest area today than in 1850).

<table>
<thead>
<tr>
<th>Percent available land for afforestation</th>
<th>status quo</th>
<th>low growth</th>
<th>medium growth</th>
<th>high growth</th>
</tr>
</thead>
</table>

1.22.7 Model Structure

The carbon sequestration of forests changes over time as the forest matures. Notice that net carbon removals are different than total removals due to carbon loss in older or unhealthy forests.

**Maximum amount of available land:** With a growing time of 80 years for new forests and 2%/year in total forest carbon loss, 700 Mha achieves an annual removal consistent with the mid-point of estimates of afforestation potential from the 2018 ‘Greenhouse gas removal’ report by the Royal Society (range of 3-20 in CO2 GtonsCO2/year).

For higher removals, one can adjust the “Afforestation settings” within the Assumptions view. For example, to explore the assumptions of the 2019 paper by Bastin et al., increase the slider “Max available land for afforestation” to 900mha under Assumptions.

1.22.8 Case Studies

New York City, USA: Increasing urban tree density by 343 trees per square kilometer was shown to reduce the rate of childhood asthma by 29% in New York City.1

Please visit support.climateinteractive.org for additional inquiries and support.

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1.23 Technological Carbon Dioxide Removal

Pull carbon dioxide out of the air with new technologies that enhance natural removals or manually sequester and store carbon. Carbon Dioxide Removal (CDR) technologies include: direct air capture, bioenergy with carbon capture and storage (BECCS), biochar, and others (but not including coal or gas CCS). CDR is not yet used widely, and most approaches face significant barriers to deployment.

1.23.1 Examples

- Advancements in various CDR technologies through research and development and government policies.
- Support from businesses, land owners, and general public to implement such technologies.

1.23.2 Big Message

- Technological Carbon Removal has the potential to pull significant amounts of carbon dioxide out of the atmosphere.
- Most of these technologies are still undergoing pilot testing, and do not exist at the level needed to deploy at a large scale.

1.23.3 Key Dynamics

- View the graphs “Land for Growing CO₂-Removal Biomass” and “Land for Farming with CO₂ Removal” and note the total amount of land area that all the approaches might require.
- View the graph “Bulk Material for Mineralization” to see the scale of industrial production these approaches entail.

1.23.4 Potential Co-Benefits of CDR Growth

- Nature-based carbon removal approaches like agricultural soil sequestration can help improve land holder and farmer profits in some cases.
- The scale up of many carbon removal approaches would result in vast new industries and businesses which would create jobs.

1.23.5 Equity Considerations

- Approaches like BECCS require large areas of land that in some cases could otherwise be used for food production.
- Many of the technological carbon removal approaches have not been developed at scale yet and pose unknown risks and consequences to the communities they are situated within.
1.23.6 Slider Settings

<table>
<thead>
<tr>
<th>Percent of maximum potential</th>
<th>status quo</th>
<th>low growth</th>
<th>medium growth</th>
<th>high growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>0% to +10%</td>
<td>+10% to +40%</td>
<td>+40% to +70%</td>
<td>+70% to +100%</td>
<td></td>
</tr>
</tbody>
</table>

1.23.7 Model Structure

The five methods of CO\(_2\) removal included are modeled independently. They each vary in their maximum sequestration potential, the year they might start to scale up, how long it takes them to be phased in, and the carbon leakage rate over time (stored carbon is not always permanent).

The default settings for the maximum potential of technological carbon removal (“% of max potential”) are sourced from the midpoint of the ranges of the 2018 ‘Greenhouse gas removal’ report by the Royal Society (Table 2, Chapter 2). For example, moving the simulator’s biochar slider to “100% of max potential” increases removals up to 3.5 Gton/yr, which was taken from the report’s range of 2-5 Gton/yr. For higher removal, one can adjust the “Carbon dioxide removal maximum” settings within the “Assumptions” view, up to the highest end of the range sourced from the same report. For example, the biochar maximum can be increased to 5 Gton/yr.

1.23.8 FAQs

Why aren’t coal and gas carbon capture and storage (CCS) included here, and how can I increase them? We think of coal and gas CCS as reducing CO\(_2\) emissions from coal and gas, not actually as removing CO\(_2\) from the atmosphere. Both can be changed in the Advanced View that supports the Coal and Natural Gas sliders.

Where can I learn more about the different CDR types? Follow the links to find detailed fact sheets on these CDR types: Agroforestry & Forestation, BECCS, Biochar, Direct Air Capture, Enhanced Mineralization, and Agricultural Soil Carbon Sequestration.

Please visit support.climateinteractive.org for additional inquiries and support.

1.24 Model Comparison - Historical

1.24.1 Table of Contents

1. Primary Energy Demand History
2. Final Energy Consumption History
3. Electricity Generated by Energy Source History
4. Marginal Cost of Wind, Solar, and Geothermal Electricity History
5. Emissions History
6. Atmospheric Concentrations History
7. Radiative Forcing History
8. Temperature History

The purpose of this section of the En-ROADS User Guide is to supplement the historical comparison graphs in the En-ROADS application by sharing multiple comparisons of En-ROADS model behavior compared against measured historical data.
En-ROADS uses historical data for two purposes: initialization of the simulation and calibration. Certain variables in En-ROADS are initialized with their measured historical values from 1990, and then the model runs. We compare the model output from 1990 through present day to measured historical data to identify opportunities for model improvement.

The graphs below compare the En-ROADS Baseline scenario to measured historical data for select variables. Not all variables and comparisons to history are included here. The historical data are derived from the following sources:


Five historical comparison graphs are also included in the En-ROADS app under Graphs > Model Comparison - Historical and are included and disaggregated here:

- Greenhouse Gas Net Emissions History
- Primary Energy Demand of Coal, Oil, and Gas History
- Primary Energy Demand of Wind and Solar History
- Marginal Cost of Solar Electricity History
- Temperature History

### 1.24.2 Primary Energy Demand History

- Total Primary Energy Demand
- Primary Energy from Coal
- Primary Energy from Oil
- Primary Energy from Natural Gas
- Primary Energy from Nuclear

Global primary energy demand of energy sources for the En-ROADS Baseline compared to IEA historical data. This is measured in exajoules per year (joules x 10^{18}/year) for electric and nonelectric sources combined.

Primary energy refers to the total energy from a raw energy source that is converted into consumable energy. For example, primary coal energy demand refers to the total energy in coal that is mined, processed, and consumed.
Primary energy is greater than final energy consumption because it accounts for inefficiencies in fuel processing, thermal conversion, and transmission and distribution (T&D).

Statistical fit

Sources of historical data


Total Primary Energy Demand
Primary Energy from Coal

![Graph of Primary Energy from Coal]

Primary Energy from Oil

![Graph of Primary Energy from Oil]
Primary Energy from Natural Gas

Primary Energy from Nuclear

Return to Table of Contents
1.24.3 Final Energy Consumption History

- Total Final Energy Consumption
- Total Final Energy Consumption - Buildings & Industry
- Total Final Energy Consumption - Transport
- Total Final Energy Consumption - Electric Buildings & Industry
- Total Final Energy Consumption - Electric Transport

Global total final energy consumption of energy sources in exajoules/year (joules x 10^{18}/year) for electric and non-electric sources combined in the En-ROADS Baseline compared to historical data.

Final energy consumption is the total energy consumed to meet the demand of all final end uses. For example, how much electricity a lightbulb uses or how much fuel a truck burns are measures of final energy consumption. It does not include transmission and distribution (T&D) losses or inefficiencies, which, in contrast, are accounted for in primary energy demand.

Final energy consumption is divided into two end uses: stationary (buildings and industry) and transport.

Statistical fit

Sources of historical data


Total Final Energy Consumption

![Total Final Energy Consumption Chart]
Total Final Energy Consumption - Buildings & Industry

Total Final Energy Consumption
Buildings & Industry

Total Final Energy Consumption - Transport

Total Final Energy Consumption
Transport
Total Final Energy Consumption - Electric Buildings & Industry

Total Final Energy Consumption - Electric Transport

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1.24.4 Electricity Generated by Energy Source History

- Electricity Generated by Coal
- Electricity Generated by Oil
- Electricity Generated by Natural Gas
- Electricity Generated by Nuclear
- Electricity Generated by Bioenergy
- Electricity Generated by Hydro
- Electricity Generated by Solar
- Electricity Generated by Wind
- Electricity Generated by Geothermal
- Electricity Generated by Other Renewables

The electricity generated by each energy source in the En-ROADS Baseline compared to historical data.

Statistical fit

Sources of historical data


Electricity Generated by Coal

![Graph showing electricity generated by coal over time, comparing En-ROADS (2021) and IEA WEO (2020).]
Electricity Generated by Oil

![Electricity Generated by Oil graph]

Electricity Generated by Natural Gas

![Electricity Generated by Natural Gas graph]
Electricity Generated by Nuclear

Electricity Generated by Bioenergy
Electricity Generated by Hydro

Electricity Generated by Solar
Electricity Generated by Wind

Electricity Generated by Geothermal
1.24.5 Marginal Cost of Wind, Solar, and Geothermal Electricity History

- Marginal Cost of Wind
- Marginal Cost of Solar
- Marginal Cost of Geothermal

The marginal cost of electricity production from wind, solar, and geothermal energy in dollars ($US 2017) per kilowatt hour (kWh) in the En-ROADS Baseline compared to historical data. This is the marginal cost for energy producers to make electricity from a new solar, wind, or geothermal installation. The cost factors in how much it costs to build new energy generation facilities (the levelized capital costs) and how much it costs to operate and maintain new facilities (O&M).

For solar, the En-ROADS Baseline is shown relative to historical data from Lazard, IRENA, and IEA. The IEA & IRENA curve is calculated from IEA (2020) capital costs per GW from 1990-2019 relative to its 2010 value, and multiplied by IRENA’s 2010 levelized cost of energy (LCOE) (2020).

For wind, the En-ROADS Baseline is shown relative to historical data from Lazard and IRENA. For geothermal, the En-ROADS Baseline is shown relative to historical data from Lazard.
Statistical fit

Sources of historical data


Marginal Cost of Wind

![Marginal Cost of Wind](image)
Marginal Cost of Solar

Marginal Cost of Geothermal

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1.24.6 Emissions History

- Greenhouse Gas Net Emissions
- CO2 Emissions from Energy
- CO2 Emissions from Fossil Fuels
- CH4 Emissions
- N2O Emissions
- F-Gas Emissions

Global greenhouse gas emissions (GHGs) in the En-ROADS Baseline and historical data, in Gigatons of CO₂ or CO₂ equivalents per year. CO₂ equivalents are used to standardize the effect of all greenhouse gases in terms of CO₂.

The Greenhouse Gas Net Emissions graph measures the total gross greenhouse gas emissions minus the total net anthropogenic carbon dioxide removal (CDR). Contributions to gross GHGs are from carbon dioxide (CO₂), nitrous oxide (N₂O), methane (CH₄), and the F-gases (PFCs, SF₆, and HFCs).


Statistical fit

Sources of historical data

Greenhouse Gas Net Emissions

CO₂ Emissions from Energy
CO$_2$ Emissions from Fossil Fuels

![CO$_2$ Emissions from Fossil Fuels](image)

CH$_4$ Emissions

![CH$_4$ Emissions](image)
**N\textsubscript{2}O Emissions**

![N\textsubscript{2}O Emissions Chart]

**F-Gas Emissions**

![F-Gas Emissions Chart]

*Return to Table of Contents*
### 1.24.7 Atmospheric Concentrations History

- **CO₂ Concentration in the Atmosphere**
- **CH₄ Concentration in the Atmosphere**
- **N₂O Concentration in the Atmosphere**

The total concentration of CO₂, CH₄, and N₂O in parts per million (ppm) of CO₂ equivalents in the atmosphere in the En-ROADS Baseline compared to historical data.

Carbon dioxide equivalents (CO₂e) are calculated from the 100-year global warming potential of each gas (IPCC AR5) for reporting purposes. Note the radiative forcing of each gas is modeled explicitly as a function of its atmospheric cycle and radiative efficiency.

#### Statistical fit

#### Sources of historical data


#### CO₂ Concentration in the Atmosphere

![CO₂ Concentration in Atmosphere](image)

- En-ROADS (2021)
- Mauna Loa (2020)
**CH₄ Concentration in the Atmosphere**

![CH₄ Concentration in Atmosphere](image)

**N₂O Concentration in the Atmosphere**

![N₂O Concentration in Atmosphere](image)

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1.24.8 Radiative Forcing History

- CO2 Radiative Forcing
- CH4 Radiative Forcing
- N2O Radiative Forcing
- Halocarbon Radiative Forcing

The radiative forcing due to CO2, CH4, N2O, and halocarbons in the atmosphere, in Watts per meter squared (W/m^2), in the En-ROADS Baseline compared to historical data. Halocarbons refer to F-gases (PFCs, SF6, and HFCs) and Montreal Protocol gases.

Greenhouse gases absorb infrared radiation and re-radiate it back, causing an increase in surface temperature. Radiative forcing measures the difference between energy absorbed by the Earth and energy radiated back into space. When incoming energy is greater than outgoing energy, RF is positive and the planet will warm.

Statistical fit

Sources of historical data


CO2 Radiative Forcing

![CO2 Radiative Forcing Graph](image)
**CH₄ Radiative Forcing**

![CH₄ Radiative Forcing Graph](image)

*Graph shows the increase in radiative forcing of CH₄ from 1990 to 2020.*

**N₂O Radiative Forcing**

![N₂O Radiative Forcing Graph](image)

*Graph shows the increase in radiative forcing of N₂O from 1990 to 2020.*
Halocarbon Radiative Forcing

Temperature change from 1850 in the En-ROADS Baseline compared to historical data, in degrees Celsius. NASA GISS (GISTEMP v5) includes the average and the lower and upper 95% confidence intervals. Met Office Hadley Centre produced the HADCRUT5 data.

Statistical fit

Sources of historical data


1.25 En-ROADS Model Version History

1.25.1 December 2021 Release

Interface Changes

- **Russian translation:** The core En-ROADS interface is now available in Russian.
- Improved sharing of the “UN Pledges” feature. When opening a shared scenario that includes the “Greenhouse Gas Net Emissions” graph, the “All Countries Follow NDCs” bar will be shown if the sender had the feature enabled.
- Corrected the types of power plants in the descriptions for the “CCS effectiveness” sliders (found under Assumptions).

Model Upgrade

- En-ROADS model to version 21.12.0
## 1.25.2 November 2021 Release

### Interface Changes

- **UN Pledges:** Added a “Show UN Pledges (NDCs)” option to the actions menu for the “Greenhouse Gas Net Emissions” graph. (Click the three vertical dots icon to reveal the menu.) When selected, a red bar will appear on the graph, indicating the approximate level of emissions in 2030 if all countries were to follow their emissions reduction pledges.

- Renamed the “Marginal Cost of Renewables—Area” graph to “Marginal Cost of Wind and Solar—Area”. The graph description now indicates that the data for “Wind & Solar” includes other renewable sources (which comprise a small percentage of capacity).

- Amended the Electrification slider descriptions to state that the Baseline scenario can contribute to electrification.

- Amended the Electrification and Energy Efficiency slider descriptions to state that the action is phased in over 10 years.

- Improved the descriptions for the “Electric demand response technology” and “Electric carrier” progress ratio sliders (found under Assumptions).

- Improved color contrast on the “Sea Level Rise—Flood Risk Map.”

- Fixed the Help > En-ROADS User Guide menu item to open the translated version of the User Guide when available (when German is the selected language, for example).

### Model Upgrade

- En-ROADS model to version 21.11.0

- Fixed an issue that caused a mismatch in the Baseline and Current Scenario lines on the “% Electricity Consumption from Qualifying Sources” graph.

## 1.25.3 October 2021 Release

### Interface Changes

- **Sea level rise maps:** Flood risk maps from Climate Central have been integrated into En-ROADS under Graphs > Impacts. These maps display the land areas that are at risk of flooding due to sea level rise, as well as the land that can be saved by actions made in the Current Scenario in En-ROADS. More details of this new feature are available in our blog post.

- **German translation:** The En-ROADS User Guide has been translated into German, and the advanced view help pages in En-ROADS now appear in German when it is the selected language.

- Added carbon budget lines to the “Net Cumulative CO₂ Emissions” graph. These lines indicate the level of accumulated CO₂ that is consistent with a 66% chance of hitting either 2°C or 1.5°C. The carbon budget lines have been updated to be consistent with recently released IPCC AR6 values.

- Removed the “Cumulative CO₂ Emissions” graph as it is redundant.

- Fixed the Actions & Outcomes view to display active policy switches (e.g., “Use clean electricity standard”).

- Corrected the variables displayed in the “Oil Primary Energy Demand—Area” and “Bioenergy Primary Energy Demand—Area” graphs to match the non-area graphs.

1.25. En-ROADS Model Version History
Model Upgrade

- En-ROADS model to version 21.10.0
- Corrected the behavior of the “Renewable Primary Energy Demand” graph when the CDR maximum for BECCS is set to zero.
- Corrected a bump in the economic damage curve when the “Reduction in GDP at 2°C” and “Maximum reduction in GDP” settings were the same.
- Fixed an issue where the Social Cost of Carbon value could go negative.
- Fixed an issue that caused a spike in the energy demand graphs when “% Reduction in coal/oil/gas utilization” is set to 100% and the “stop year” is set earlier than 2100.

1.25.4 September 2021 Release

Interface Changes

- **Climate impacts**: Five new bar graphs have been added under the Graphs > Impacts menu showing the effects of climate change:
  - Population Exposed to Sea Level Rise
  - Probability of Ice-free Arctic Summer
  - Decrease in Crop Yield from Temperature
  - Species Losing More than 50% of Climatic Range
  - Additional Deaths from Extreme Heat
- **Graph actions menu**: A new contextual menu is available by clicking the “three dots” icon to the right of a graph title. The menu reveals actions related to the graph:
  - Show Description
  - View Larger
  - View in New Window
  - Copy Data to Clipboard
- Updated the range for the “Climate sensitivity” slider to match the new AR6 findings from the IPCC.
- Revised the description for the “Social discount rate” slider.
- Improved handling of scenario links with invalid parameters. When opening a link created with an older version of En-ROADS, if any parameters are no longer valid, a warning will be displayed showing which sliders are affected (instead of resetting the entire scenario).
Model Upgrade

• En-ROADS model to version 21.9.0
• Fixed the model so that the “HFC phase out start year” slider has an effect only when the “Use detailed settings” switch is active.

1.25.5 August 2021 Release

Interface Changes

• **Japanese translation**: Additional graph and slider descriptions have been translated into Japanese.
• To avoid redundancy, air pollution parameters have been consolidated under Assumptions > Air pollution with a single slider for each fuel type. This does not change model behavior.
• Adjusted the y-axis range on several graphs to better display their plots.
• Matched the y-axis maxima for pairs of graphs that display “Total” and “by Source—Area” information so they are more easily compared.
• Improved the descriptions for the “Nuclear R&D breakthrough cost reduction” slider and the Bioenergy view.
• Removed a redundant slider for methane leakage from the Natural Gas advanced view. The other slider is found in the Methane & Other Gases advanced view.

Model Upgrade

• En-ROADS model to version 21.8.0
• Corrected an error in the energy utilization sector which was causing the price of electricity to increase and preventing renewables from growing as they should in the absence of fossil fuel utilization.
• Corrected an equation which omitted the hydro-generated energy from the “Renewables” plots in the “Final Energy Consumption” graphs.

1.25.6 July 2021 Release

Interface Changes

• **Arabic translation**: The core En-ROADS interface is now available in Arabic.
• **COVID-19 impacts**: Added a set of eight new sliders (under the Assumptions > COVID-19 impacts heading) for controlling the assumptions about the impacts of the COVID-19 pandemic on greenhouse gas emissions and other model parameters.
• Removed the “Average Cost of Electricity Production” and “Low-Carbon Average Cost of Production” graphs. (Utilization in the model no longer depends on average costs, so the marginal cost graphs are more useful.)
• Corrected the y-axis range of the “Land for Growing CO₂-Removal Biomass” and “Land for Farming with CO₂ Removal” graphs.
Model Upgrade

- En-ROADS model to version 21.7.0
- Added structure to model the effects of the COVID-19 pandemic on the global economy, energy demand, and other indicators.

1.25.7 June 2021 Release

Model Upgrade

New

- Added structure for clean electricity standard and social cost of carbon to the En-ROADS model.
- Transmission and distribution costs for electricity are now included in the variable costs to produce the electricity.

Updated

- En-ROADS model to version 21.6.0
- Note that starting with this release, the model version number is now based on the date of the release (for example, 21.6 refers to the sixth month of 2021).

Interface Changes

New

- **Japanese translation:** The core En-ROADS interface is now available in Japanese.
- **German translation:** Additional graph and slider descriptions have been translated into German.
- **Clean electricity standard:** Added new features to the “Carbon Pricing and Energy Standards” advanced view:
  - Activate the clean electricity standard policy with a switch and adjust the settings of the policy with multiple new input sliders.
  - Control the types of energy sources that qualify for the clean electricity standard.
  - New graph “% Electricity Consumption from Qualifying Sources” has been added to the Final Energy Consumption Types group.
- **Social cost of carbon:** Added new table for the social cost of carbon in the Population & GDP group.
- Added transport electrification sliders to separate out transport based on land (road and rail) from transport based in air or on water.
Updated

- Added a link to view more historical graphs in the Model Comparison—Historical group.
- Added a new button (on the main view and under the Help menu) that links to the web page for registering your En-ROADS events.
- Added a line to compare the trajectory of HFCs with the Kigali Amendment to the Montreal Protocol on the “SF₆, PFC, and HFC Emissions” graph.
- Added the “SF₆, PFC, and HFC Emissions” graph to the list of related graphs in the “Methane & Other Gases” advanced view.
- Added the version number to the lower right corner of the interface.
- Removed “beta” references from the interface.
- Reordered graphs in the Model Comparison—Historical group.
- Improved graph and slider descriptions.

1.25.8 May 2021 Release

Model Upgrade

Updated

- En-ROADS model to version 2.7.39
- Updated data for non-CO₂ GHGs through 2018 using PRIMAP 2.2.

Interface Changes

New

- **Translation into French:** En-ROADS is now available in French.
- **Graph replacements:** Because of differences in carrier efficiencies, the percent of capital that is electric is not the same as the percent of final energy for that capital. We have therefore changed the associated graphs from “Electric Share of Final Energy” to “Electric Share of Capital” for Buildings & Industry and for Transport.
- We have rearranged the ordering of the Simulation > Assumptions sliders to follow the relative order of the slider groups on the En-ROADS main view.

Updated

- Various small text edits to graph and slider descriptions.
1.25.9 April 2021 Release

Model Upgrade

Updated

- En-ROADS model to version 2.7.38
- Added model structure for carbon dioxide removal (CDR), carbon capture and storage (CCS), and economic impact of climate change on GDP.

Interface Changes

New

- **Structural upgrades to the user interface:** We have updated the underlying architecture of En-ROADS to allow future feature additions to be added more easily. You will not see any functional differences in the operation of En-ROADS or in the interface layout of En-ROADS. There are some aesthetic improvements and multiple changes that make the simulation easier to operate. User experience improvements include:
  - The currently selected graph is indicated in the graph selection menu.
  - Sliders and menus work better on a wider variety of touchscreen devices (no more touchscreen warnings).
  - The interface is more responsive when resizing the browser window.
  - The simulation loads faster.
  - The Actions & Outcomes view size adapts to its contents.
  - Many other subtle additions that will enhance the usability of the simulation.
- **New Assumptions slider for social discount rate:** We have added a new input slider, “Social discount rate,” under the Assumptions > Economic impact of climate change heading. The effect of changes to the social discount rate are displayed in a new graph, “Global GDP Loss” and in the Actions & Outcomes table as “Discounted Cumulative Damage through 2100.”
- **New Assumptions slider for fossil fuel CCS leak rate:** We have added a new input slider, “Fossil fuel CCS leak rate,” under the Assumptions > Carbon capture & storage (CCS) effectiveness heading. This slider allows the user to test non-zero leak rates for fossil fuel CCS.
- **New graphs added to the simulation:**
  - In the Removals and Land Use group:
    - Annual Volume of Captured CO₂
    - Cumulative Storage of CO₂
  - GDP-related graphs relocated to the Population & GDP group:
    - Reduction in GDP vs Temperature
    - Reduction in GDP from Climate Impacts
  - New GDP-related graphs also under the Population & GDP group:
    - GDP per Capita Growth Rate
    - Global GDP Loss (which also shows the discounted value of economic damage)

Read more in our blog post about climate impacts on GDP.
• **New historical comparison graphs:** There is a new graph menu group, Model Comparison—Historical. These graphs compare historical data to En-ROADS simulation output from 1990-2020.
  – Temperature History
  – Marginal Cost of Solar Electricity History
  – Primary Energy Demand of Coal, Oil, and Gas History
  – Primary Energy Demand of Wind and Solar History
  – Greenhouse Gas Net Emissions History

• **Added Spanish translations** of graph and slider descriptions.

### 1.25.10 March 2021 Release

**Model Upgrade**

**Updated**

• En-ROADS model to version 2.7.37
• Added model structure for economic impact of climate change on GDP.

**Interface Changes**

**Fixed**

• Improved the colors on the “Renewables Capacity — Area” graph to make the plots easier to distinguish.
• Changed the Simulation > Assumptions > Climate sensitivity > “Sea level rise from ice sheet melting” slider label to “Additional sea level rise from ice sheet melt” and edited its associated description text for greater clarity.

**New**

• **Translation into Italian:** En-ROADS is now available in Italian.
• **New slider for Economic impact of climate change:** A new slider type with two input “handles” has been added to the Assumptions menu: Economic impact of climate change. The two handles control “Reduction in GDP at 2°C from climate impacts” and “Maximum reduction in GDP.”
• Two new “Climate impact on GDP” related graphs have been added under the Impacts header:
  – Reduction in GDP vs Temperature
  – Reduction in GDP from Climate Impacts
• Read more in our [blog post](#) about the economic impact of climate change in En-ROADS.
• Added an Assumptions slider for the progress ratio of electrifying transport, buildings, and industry under Simulation > Assumptions > Progress ratio > Electric carrier.
1.25.11 February 2021 Release

Model Upgrade

Updated

- En-ROADS model to version 2.7.36
- Updated temperature change data and reference years using new temperature data update in HADCRUT5 dataset from December 2020.
- Modified En-ROADS to use baseline data from C-ROADS that is fed into the En-ROADS data model for initialization.
- Updated profitability effects to avoid getting too large with extremes that were leading to drastic and unrealistic swings that could be seen in capacity, utilization, and pricing.
- PRIMAP 2.1 data (2019) of historic GHG emissions were used to update initial fractions of each non-CO₂ GHG emissions from agriculture, waste, extracted fuel supply, demand capital, and non-CO₂ GHG emissions from energy use) and to improve calibration.
- Improved and simplified CH₄ concentration calibration to avoid unnecessarily introducing more uncertainty in response to CH₄ concentration effects on uptake and to include updated PRIMAP data.

Fixed

- Resolved unexpected bioenergy demand spikes that had appeared in the previous release for some scenarios.

Interface Changes

New

- Four new translations: New translations added for simplified Chinese, traditional Chinese, German, and Bulgarian. More languages on the way in March!
- New graphs: New graphs added related to enhanced mineralization and other carbon removal approaches:
  - Land for Growing CO₂-Removal Biomass
  - Land for Farming with CO₂ Removal
  - Bulk Material for Mineralization
For more details about the carbon removal approaches displayed in these new graphs see this related blog post.
- Added new assumptions specific to enhanced mineralization (found in Assumptions > Mineralization settings).
- Relocated the Language menu to the first menu position and included a globe icon as an indicator for the menu.
Fixed

- Changed terminology from “mid-19th century” to 1850.
- Adjusted some graph and slider labels for better fit in translations.

1.25.12 January 2021 Release

Interface Changes

New

- **Translation into Turkish**: We have a new translation into Turkish this release. Check it out under the Language menu.
- **New graph**: Added a new graph, “% Electricity Consumption from Low-Carbon Sources”. Find it under “Final Energy Consumption Types” under the Graphs menu.
- Corrected all references to Purchasing Power Parity to $US 2017. Other various text edits.

1.25.13 December 2020 Release

Read more details about the update.

Watch a video overview of the details of the update.

Model Upgrade

New

- **Updated Baseline**: Several model adjustments related to renewable energy sources, pre-industrial temperature benchmarking, and modeling of non-greenhouse gas forcings have lowered the baseline temperature in 2100 to 3.6°C/6.5°F.
- Renewables are now disaggregated and explicitly modeled for solar, wind, geothermal, and other renewables.
- We also account for the historical subsidies for renewables and the “soft costs” associated with each renewable type. These soft costs have declined as experience was gained.
- The temperature change reported is now relative to the 19th century.
- Initial heat is now calculated from historic temperature change in 1990, taken from temperature anomaly relative to 19th century from GISS (2020) and Hadley (2020) and adjusted to be relative to 18th century mean.
- Other forcings taken from Meinshausen (2011) to reflect those relative to 18th century. Natural forcings easier to subtract to obtain anthropogenic forcings for Equivalent CO$_2$ concentration.
- Initial CO$_2$, CH$_4$, and N$_2$O updated to reflect actual data from GISS instead of C-ROADS 1990 values.
- Decrease in extraction overheating sensitivity and profitability effects on retirement rates of supply sources to dampen rapid changes in bioenergy demand.
Updated

- En-ROADS model to version 2.7.35c

Interface Changes

New

- **New default graphs**: Changed the default graphs from “Global Sources of Primary Energy” and “Temperature Change” to “Global Sources of Primary Energy — Area” and “Greenhouse Gas Net Emissions”.
- Added several graphs related to renewable energy:
  - “Low Carbon Average Cost of Electricity Production by Source”,
  - “Low Carbon Marginal Cost of Electricity Production by Source”, and
  - “Renewables Capacity — Area”.
- Changed the phrase “Business as usual” and “BAU” to “Baseline” across the interface, graphs, legends and descriptions.
- Changed the population input slider to display “billion people in 2100” instead of the -1 to +1 index range.
- Expanded the inputs for Economic Growth from a single input to now include “Long-term economic growth”, “Near-term economic growth” and a “Transition time” for the “Near-term economic growth” to converge on the “Long-term economic growth” rate.

Fixed

- Changed the start year for input sliders to 2021.
- The ranges for Tax/Subsidy sliders have been updated.
- Some graph descriptions have been edited for clarity.
- Adjusted the Y-axis maximum on some graphs to display the data better over different input configurations.

1.25.14 October 2020 Release

Model Upgrade

Updated

- En-ROADS model to version 2.7.29b
- Corrected the “New Tech” plot in the “Marginal Cost of Electricity Production” graph when the “New Technology” advanced sliders are adjusted.
Interface Changes

Fixed

- Added a short description at the top of the Assumptions panel to clarify how the sliders behave relative to the “Current” and “Business as Usual” scenarios.
- Fixed descriptions of transport electrification sliders to remove mention of ships and airplanes.

1.25.15 September 2020 Release

In addition to the details listed below, we’ve made a video highlighting the important new features.

Check it out: September 2020 Release Video

Interface Changes

New

- Spanish: En-ROADS is now available in Spanish! We’re working to bring En-ROADS to even more languages too.
- Air Pollution graphs: There are two new graphs in the “Graphs > Impacts” menu showing Air Pollution (PM2.5 Emissions) from the energy sector. Additionally, sliders were added in the “Assumptions” panel to allow for adjusting the emission factor assumptions.

Model Upgrade

Updated

- En-ROADS model to version 2.7.29

Control Slider Related Changes

Updated

- Changed the population slider units to be on -1 to 1 indexed scale with “status quo” equal to zero.
- Fixed the units of the Carbon Price slider to read “$/ton CO_2” instead of “$/ton”.

Other Interface Changes

Updated

- Fixed the Kaya view to show “Carbon Intensity of Final Energy” instead of “Carbon Intensity of Primary Energy”.
- Fixed the menu bar to make it easier to select sub-menu items on iPad.
- Fixed tooltips on iPad so that they disappear automatically.
- Fixed alignment of slider handles on iPad.
• Fixed full screen layout on iPad so that the menu bar is not obscured by the Safari-provided controls.
• Fixed the large graph window to display in the current language (instead of defaulting to English).
• Fixed the x-axis labels on Kaya graphs to not overlap on large screens.
• Fixed graphs to not show tooltips for years outside the displayed range.
• Removed calibration graphs (these will be replaced by improved graphs in an upcoming release).

1.25.16 August 2020 Release

Interface Changes

New

• Portuguese: En-ROADS is now available in Portuguese! Localization to more languages is in progress, and we hope to come to your native language soon.
• Initial iPad Support: You can now run En-ROADS on your iPad (in Safari or your preferred browser)! In this release, the user experience is better on iPad models released in the last 3 years. In upcoming releases, we will be working to improve performance and refine the user experience across all iPad models.

Updated

• Improved performance in a number of areas, so sliders should feel smoother and more responsive (and further improvements are in the works).
• When sharing a scenario, the user’s preference for Metric vs U.S. Units is captured and remembered in the URL.

Control Slider Related Changes

Fixed

• Updated the “Carbon Price” slider description to include bioenergy in the list of impacts.
• Removed accidental mention of deforestation in the “Other greenhouse gases start year” slider description under “Methane & Other Gases”.

1.25.17 July 2020 Release

Graphs

Fixed

• Corrected the y-axis of the “Marginal Cost of Electricity Production” graph to adjust dynamically to keep graph lines in view.
• Corrected the “Renewables Primary Energy Demand” graph to reflect hydro in addition to renewables.
Control Slider Related Changes

Fixed

• Improved descriptions for the “Year to stop building new infrastructure” sliders for coal, oil, and natural gas.

Other Interface Changes

Updated

• Improved email sharing of scenarios by showing a preview of the message to be sent, and allowing for a custom note to be included with the shared scenario.
• Changed the welcome screen to direct feedback and questions to support.climateinteractive.org.
• Changed the “General FAQs” link under the Help menu to direct to the Knowledge Base on the support site.

1.25.18 May 2020 Release

Model Upgrade

Updated

• En-ROADS model to version 2.7.19
• Add email sharing of your current scenario to “Share Scenario” menu button.
• Update GDP with 2018 World Bank data.

Fixed

• Minor edits to description texts

1.25.19 April 2020 Release

Model Upgrade

Updated

• En-ROADS model to version 2.7.14
• Added link to “Uses for En-ROADS” under the Help menu
• Add menu control for “Reset Policies” sliders and “Reset Assumptions” sliders under “Simulation” menu; changed wording of “Reset” to “Reset Policies & Assumptions.”
Graphs

- When switching from Metric Units to U.S. Units, the “Land for Carbon Dioxide Removal” graph switches from “Million hectares” to “Million acres”.

Fixed

- Improved location of icons in the top toolbar to help avoid accidental clicks on the “Reset Policies & Assumptions” icon (formerly, “Reset sliders” tool tip).
- Correcting Large graph feature so graphs are sized correctly in the remote window.
- Edits to description texts for “Coal carbon capture & storage (CCS) (tax/subsidy)” slider, “Gas carbon capture & storage (CCS) (tax/subsidy)” slider and the overall description for Nuclear in the advanced views.

1.25.20 March 2020 Release

Along with the details listed below, we’ve made a cool video highlighting the important feature additions and changes to model behavior.

Check it out: March 2020 Release Video

Model Upgrade

Updated

- En-ROADS model to version 2.7.11
- Updated the equation for the Energy Intensity of New Capital to better respond to price effects
- BAU improvement rate in emission intensity and Annual improvement rate of emission intensity for F-gases were adjusted to reflect SSP2 baseline trajectories
- The settings for CH₄ and N₂O emissions from agriculture and waste have also been slightly updated

Graphs

Fixed

- Add “Hydro” data to “Average Cost of Electricity Production” graph and correct the name of “Renew/Hydro” to Renewables”
- Corrected several missing Related Graphs in some advanced views
- Corrected the variable in “Marginal Cost of Renewables” graph
- Corrected typo in descriptions for N₂O and CH₄ graphs (Megatons was corrected to 1x10⁶)
- The y-axis label in graph “CO₂ Emissions” was corrected to Gigatons CO₂/year
Updated

- Edited the description for “CH₄ Emissions” graph and corrected the plotted variable to display anthropogenic CH₄ emissions
- Edited “Storage Costs” graph description for clarity
- Edited the description for “Cumulative CO₂ Emissions” graph
- Changed the graph name from “Fuel Production Cost” to “Fuel Production Cost by Source” to make it consistent with the titles of the other graphs in the Financial category that are broken out by energy source
- Added “Greenhouse Gas Net Emissions by Gas—Area” to related graphs for Deforestation

Control Slider Related Changes

Fixed

- Updated New Tech slider description to match what the slider settings do
- Added back a missing description for slider, “Coal CCS R&D breakthrough cost reduction”
- Edit description for slider, “% Reduction in Coal Utilization”

Updated

- Edit slider names referring to final carbon price, removing the word “target” so it is now:
  - Final carbon price (previously, Final Carbon price final target)
  - Year to start achieving final carbon price (previously, Year to start achieving final carbon price target)
  - Years to achieve final carbon price (previously, Years to achieve final carbon price target)
- Added back assumptions sliders for “Methane emissions from biological activity”, “Effect of temperature on methane emissions from permafrost and clathrates”, and “Temperature threshold for permafrost and clathrates”

Other Interface Changes

New

- You can create a large copy of any of the graphs to use on additional screens or monitors. The graph outputs in the copies remain connected to changes in the control input sliders. These graphs are accessed under the View menu, as “Large Left Graph and “Large Right graph”. You may select multiple copies of left or right graphs.

Coming Soon

- Localization to many languages is in process! We hope to come to your native language soon!
CHAPTER
TWO

INDICES AND TABLES

• genindex
• modindex
• search